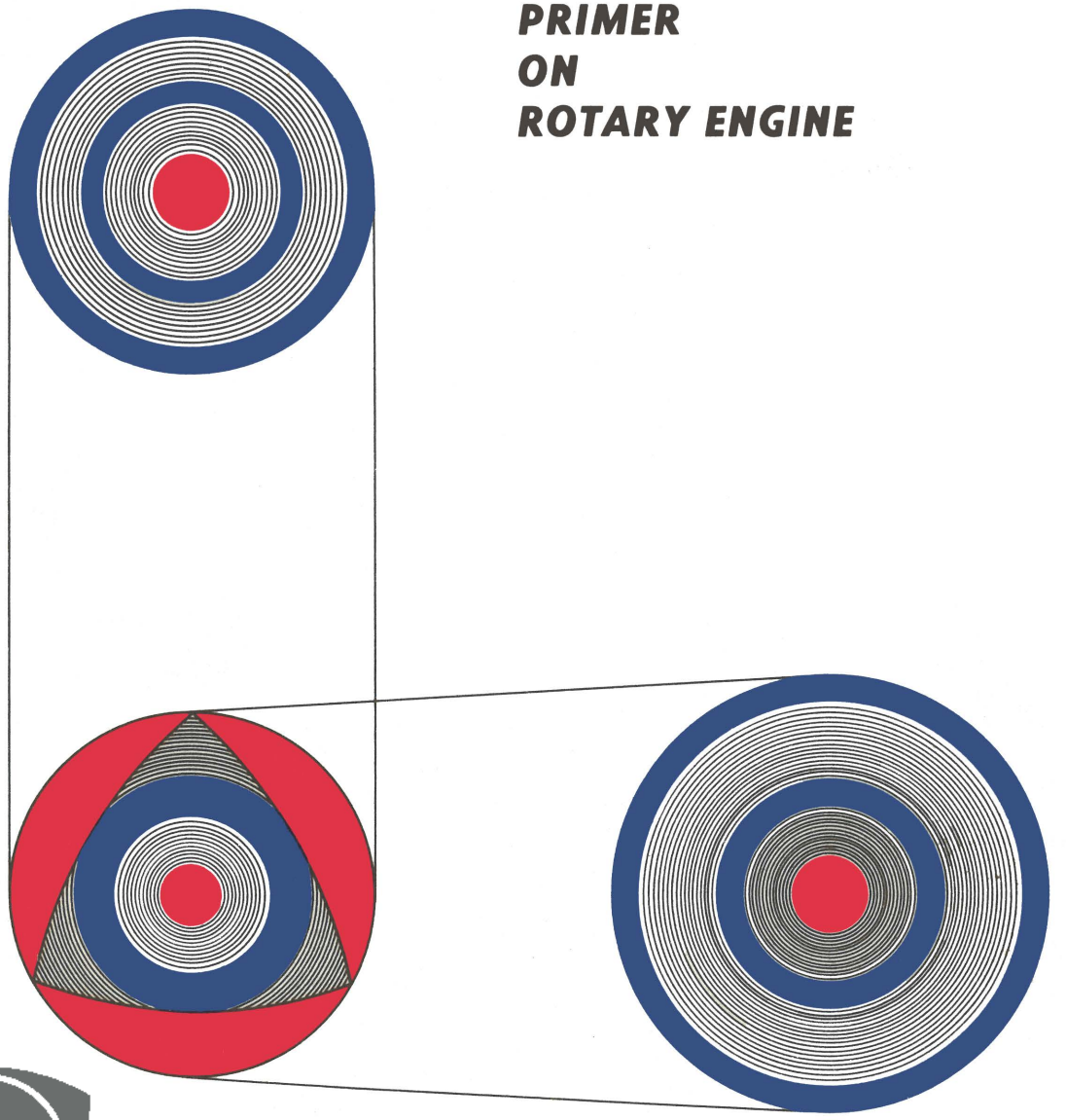
SUZUKI

WANKEL R.E. FUNDAMENTALS

PRIMER
ON
ROTARY ENGINE



FOREWORD

The rotary engine is a newcomer in the world of internal combustion engines—a world almost 90 years old if we take Gottlieb Daimler's hot-tube reciprocating engine of 1883 as the first of the kind. This newcomer deviates markedly from the conventional reciprocating engine concept, as far as the method of imparting the expansion power of burning fuel to the output shaft. How and in what details the rotary engine (R.E.) deviates are the side theme of this manual.

The manual has been prepared for those who are to service the Model RE-5 SUZUKI motorcycle powered by the SUZUKI R.E. It covers the basic matters regarding the working principles and construction features of the SUZUKI R.E. Also dealt with are the points of difference between this new R.E. motorcycle and those that SUZUKI has long been turning out from its motorcycle production plants.

Not included are the handling and servicing techniques for the SUZUKI R.E. and its specific data. These are covered in the usual manner in the owners' and service shop manuals.

It is hoped that the R.E. fundamentals set forth in this manual, as based on the engine of the Model RE-5 motorcycle, will spur the reader's curiosity on the R.E. and will lead him to further study of the subject, for we believe that effective servicing stems from a full understanding of what is serviced.

SUZUKI MOTOR CO., LTD.
International Service Department

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1. WORKING PRINCIPLES AND BASIC CONSTRUCTION OF THE R.E.

1-1. How does the R.E. run?

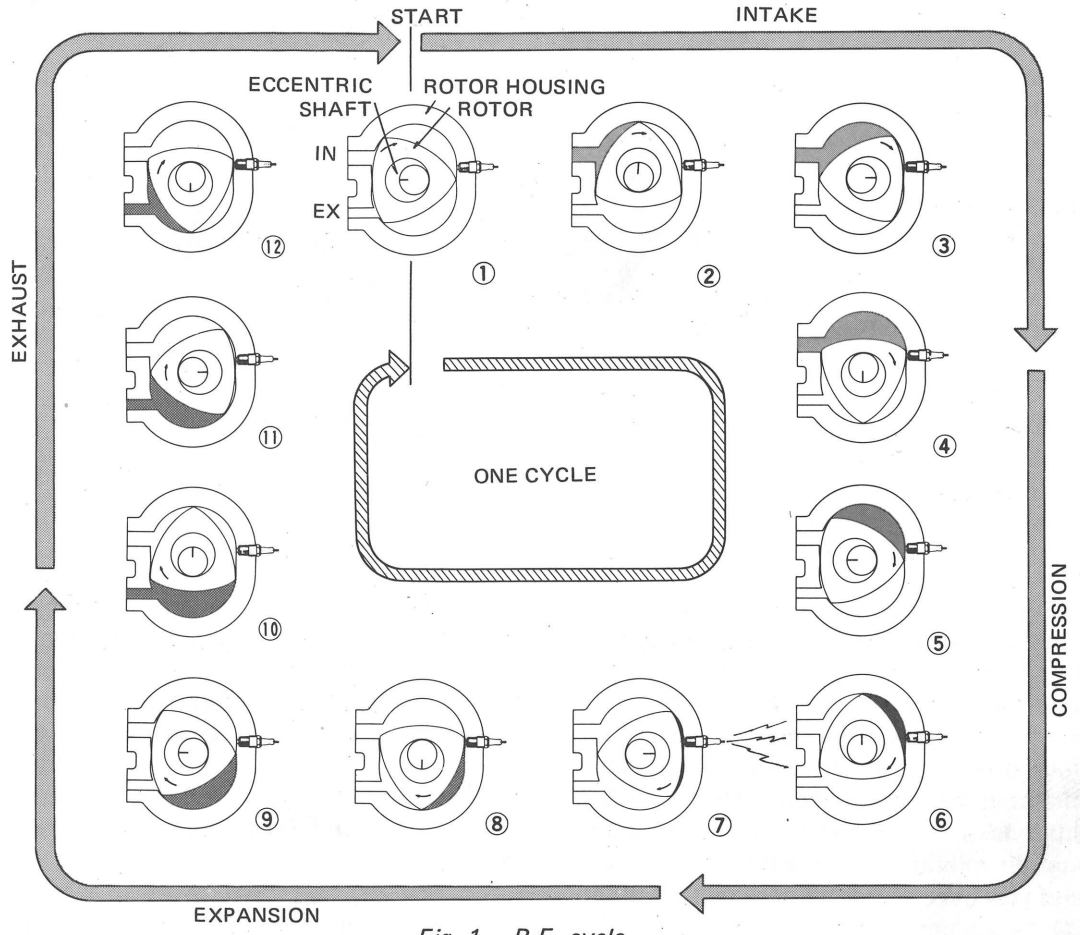


Fig. 1 R.E. cycle

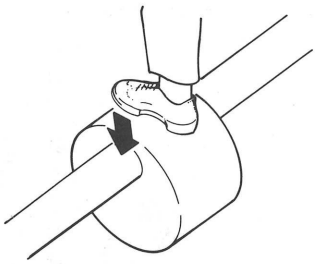
Looking at Fig. 1, you will offhand note three salient points: (1) there are three chambers around the rotor; (2) the rotor rotates and revolves; and (3) the bore in which the rotor runs is somewhat oval.

Let's view the behavior of the chambers closely. First, they are 120° apart and they shift their positions as the rotor runs. Fig. 1 draws our attention to one of the three chambers and illustrates how this chamber undergoes changes in state —volume and position.

At a given moment during one-cycle movement of the rotor, the three chambers are involved, respectively and simultaneously, in SUCTION, COMPRESSION, EXPANSION and EXHAUST.

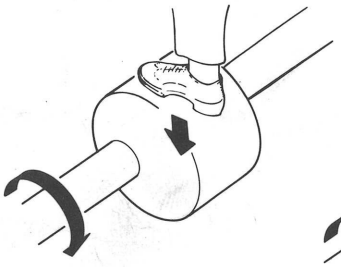
Note that the rotor is supported by a shaft—eccentric shaft. This shaft is the output shaft. Since the rotor is on the eccentric shaft, which obviously rotates on its axis, the rotor revolves as well as rotates. You will readily realize that this composite motion of the rotor **must** be such as to enable the three chambers to change their shapes as they shift around. How this requirement is met will become clear in the pages following this. Let it suffice here to say that, for each one-cycle movement of the rotor, the eccentric shaft rotates three times.

1-2. How is power transmitted to the eccentric shaft?



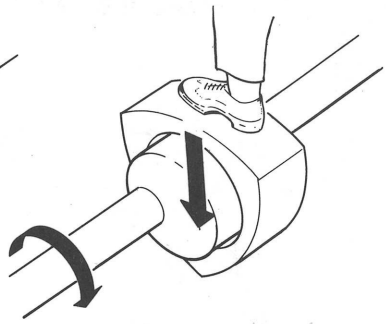
NO TORQUE
DEVELOPS.

Fig. 2



TORQUE IS
BEING DEVELOPED.

Fig. 3



ROTOR DEVELOPS
TORQUE BUT IT HAS
TO MOVE SIDEWISE.

Fig. 4

In Fig. 2, you give a downward push to the eccentric shaft but nothing happens. In Fig. 3, leverage comes into play, and the shaft will turn. In Fig. 4, you have the triangular rotor mounted on the shaft; your downward push exerted on the top chamber face of the rotor will cause the shaft to turn. Replace your foot by the fuel-air mixture that has been detonated, and you have a rudimentary picture of the R.E.—rudimentary but not complete.

Referring again to Fig. 4, imagine a rotary engine based on the one-chamber principle making use of only one face of the three. Such an engine will run; it is similar to a piston-rod-crank design of the conventional reciprocating engine: the rotor, however, has to rock laterally or sidewise as it moves up and down, always holding a particular one of the three faces on the top side. Then the rotor is not a rotor any more.

So, we discard this hypothetical engine, and seek a scheme which will make the rotor rotate to close in on the true R.E. concept.

1-3. Why and how should the rotor rotate?

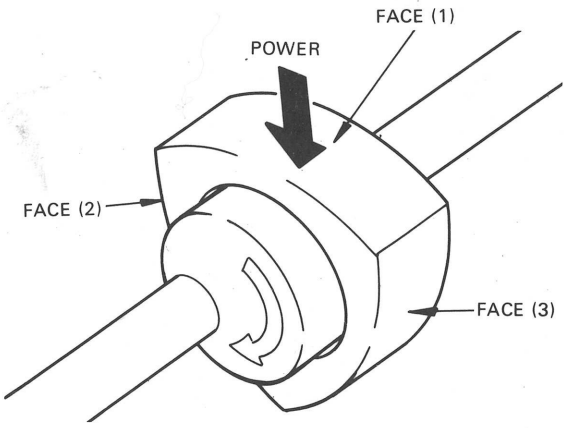


Fig. 5

In the imaginary one-chamber engine mentioned above, the eccentric shaft rotates **once** for each fuel-air explosion. We want a better scheme than that. Now look at Fig. 5. Face No. 1 is receiving power. Can't we make face No. 2 receive power immediately after the eccentric shaft has completed one rotation and brought its bulge to the same or original position? To do so, we have to turn the rotor 120° (1/3 rotation) around the eccentric shaft. If this is possible, then we can turn the rotor another 1/3 rotation to bring face No. 3 too to the power-receiving position. Setting aside the question of how to prepare the compressed fuel-air mixture, we can say that, by turning the rotor 360° in steps of 120° each, we can give a downward push (in Fig. 5) to each of the three faces in succession. And, obviously enough, the eccentric shaft will be in the position shown in Fig. 5 for **each** power reception by the rotor.

Thus, we may say that the eccentric shaft rotates 3 times for each rotation of the rotor around it. We are now closer to the true R.E. concept, but there is another immediate question: how to mechanically relate the two — rotor and shaft — for producing 1-to-3 rotary movements.

1-4. Where does the force for rotating the rotor come from?

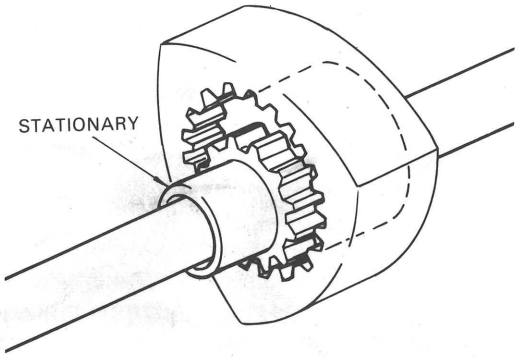


Fig. 6

You might have guessed by now that the downward push or the power available from the exploding mixture of fuel and air is just a downward force and does **not** act to **rotate** the rotor; it merely pushes down on the rotor. Your guess is right. But the downward motion of the rotor causes the eccentric shaft to rotate; we have already seen this plainly in Figs. 3, 4 and 5.

Why not utilize the rotary motion of the shaft to **rotate** the rotor? It can be and is done as shown in Fig. 6.

Machine out internal gear teeth in the bore of the rotor, locating the teeth away from that part of the bore in sliding fit on the shaft; install a pinion-like gear into this toothed bore, meshing its teeth with those of the rotor in the manner shown in Fig. 6, and locating its axis in alignment with the axis of the eccentric shaft; and, what is important, fixate or rigidly secure this pinion-like gear to a non-rotary member (such as the housing).

It should be recalled here that the rotor **revolves** because it is mounted on the eccentric shaft. Now, forget all about the three faces or triangular contour of the rotor in Fig. 6 and just **cast your attention to the internal gear teeth.** On the screen of your mind, let that circle of internal teeth **revolve.**

The circle has to rotate! Because its teeth are meshed with those of the fixated gear. In other words, the revolving rotor is compelled to "roll" around the fixated gear.
The next question is then the gear ratio.

1-5. What is the required gear ratio for 1-to-3 relationship?

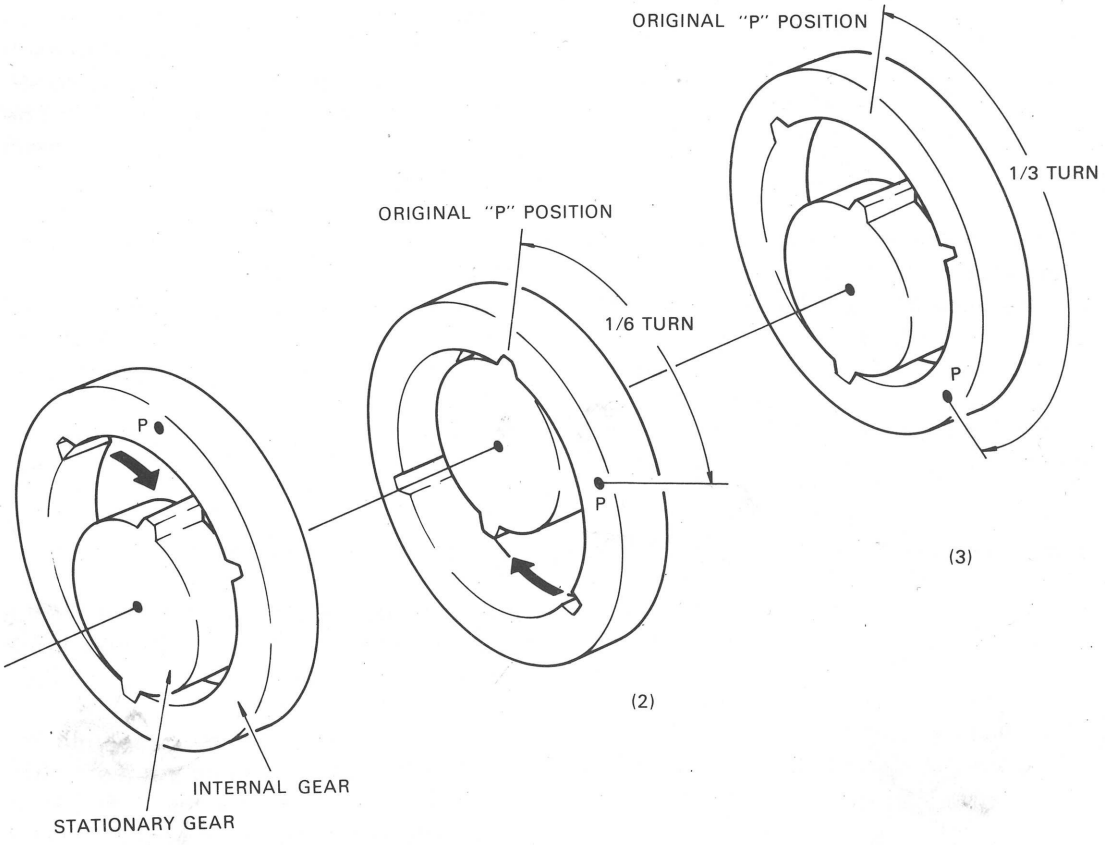


Fig. 7

On this topic, we start out with the conclusion: To make the rotor **rotate** once for each three rotations of the eccentric shaft, the ratio, in terms of the number of teeth, of the internal teeth to the external teeth, that is, of the rotor to the fixated gear must be **3 to 2** (3:2). Why so will be explained by simplification.

A simplified case is shown in Fig. 7. The reference point on the rotor is marked "P". Keeping that point in mind, let the internal gear **roll** around the fixated gear, following the change of state from Fig. 7 (1) through Fig. 7 (2) to Fig. 7 (3). For **one revolution** of the rotor, it **rotates** 120° (1/3 rotation)! For **three** revolutions of the rotor, it rotates 360° (**one** complete rotation). This ratio is 3:1, as we wanted.

Let's go back to the beginning: the rotor makes the eccentric shaft **rotate**; the shaft in turn makes the rotor **revolve** and thereby compels the rotor to **rotate.** Since this statement is true, we can say we have thus succeeded in utilizing the rotary motion of the eccentric shaft to **rotate** the rotor!

1-6. How much space does the rotor need to rotate and revolve?

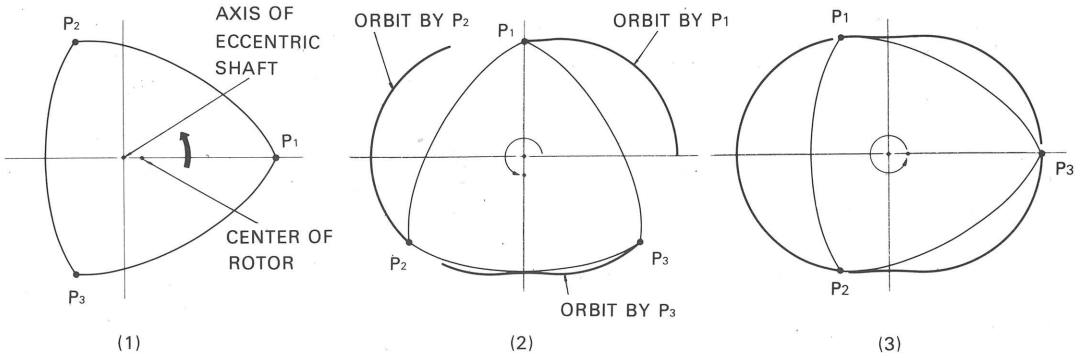


Fig. 8

We have seen that 1) the rotor **revolves** around the axis of the output shaft (eccentric shaft) and 2) the rotor **rotates** around the **center** of the bulged portion of the shaft. We have thus been focussing our attention to the circular movements. Let's pose another question: How much plane space does the rotor need?

If the rotor were a perfect circle in contour, the answer to this question would be found in no time; but the rotor is triangular and has three apexes to complicate the matter.

Our intuition tells us that the space the rotor needs will be defined by these three protruding points. Fig. 8 is an attempt to show how these points—apexes—describe the space in which the rotor runs.

The rotor is originally in the position given in Fig. 8 (1), with its apex P_1 on the right. Let the rotor turn ccw exactly three quarters (3/4) revolution to the position shown in Fig. 8 (2). How much has the rotor rotated during this 3/4 revolution? By simple arithmetic on the basis of the 1:3 ratio, we find that it has rotated 90° or a quarter rotation (1/4 = 3/4 x 1/3).

The movements of the apexes P_1, P_2 and P_3 are traced in Fig. 8 (2). Now, turn the rotor a quarter revolution to the position shown in Fig. 8 (3). The rotor has completed one revolution and one-third (1/3) rotation.

The orbits of P_1, P_2 and P_3 for the transition from Fig. 8 (2) to (3) are traced. Note that the three orbits connect to one another to form a symmetrical loop. This loop is for **one revolution** and **one-third rotation** of the rotor. For each subsequent rotor revolution, the three apexes will move along the same loop. The area bounded by the loop is the space needed by the rotor. This conclusion in turn suggests the shape needed of the bore to be formed in the rotor housing.

1-7. How is the bore of the rotor housing shaped?

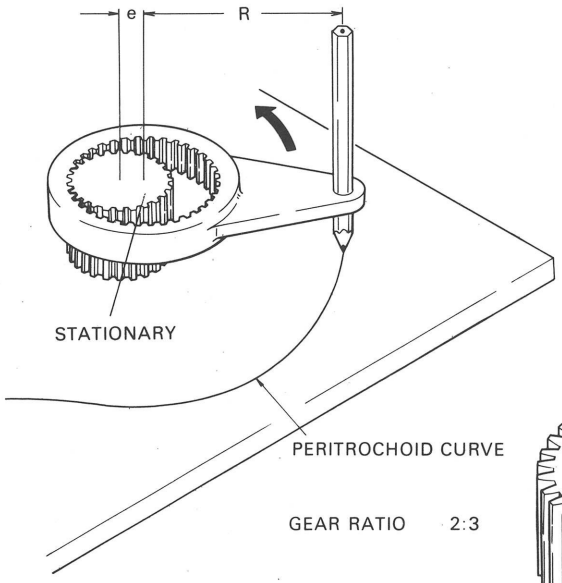


Fig. 9

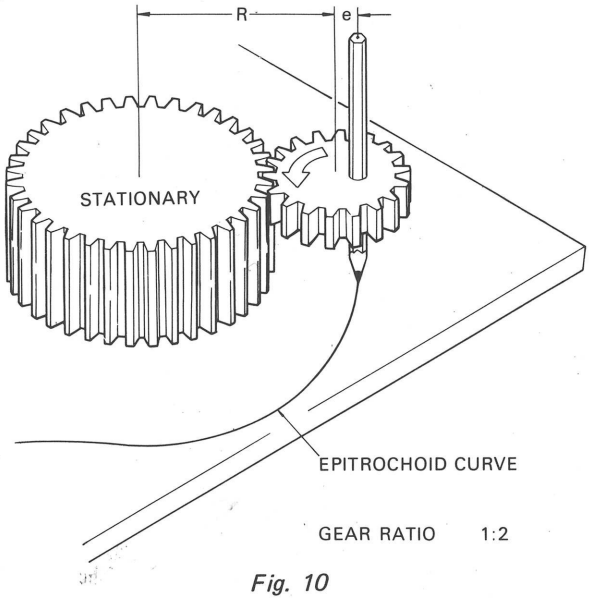


Fig. 10

A trochoid is the curve described by any point of a circular shape which is rolling on a flat, straight surface. An epitrochoid and a peritrochoid are but modifications of the trochoid. The prefix "epi" is for OVER or ABOVE; the "peri" is for AROUND or NEAR.

A peritrochoid is being drawn in Fig. 9; an epitrochoid in Fig. 10. Two radii are involved: "e" is for **eccentricity** and "R" is for **generating radius.**

A very striking fact is that, where the lengths of "e" and "R" are respectively equal in both instances (Fig. 9 and Fig. 10), the resultant peritrochoid and epitrochoid are identical!

The apex of the rotor corresponds to the pencil point. Thus, the loop described in Fig. 8 is similar to the trochoidal loops drawn in Fig. 9 and Fig. 10. The profile contour of the housing bore is determined by the technique illustrated in these figures. Theoretically, one set of "e" and "R" is used for both rotor and bore.

We have been considering the apexes. What about the shape of the three sides of the rotor? Are the sides determined arbitrarily? This question will be answered next.

1-8. How is the rotor shape determined?

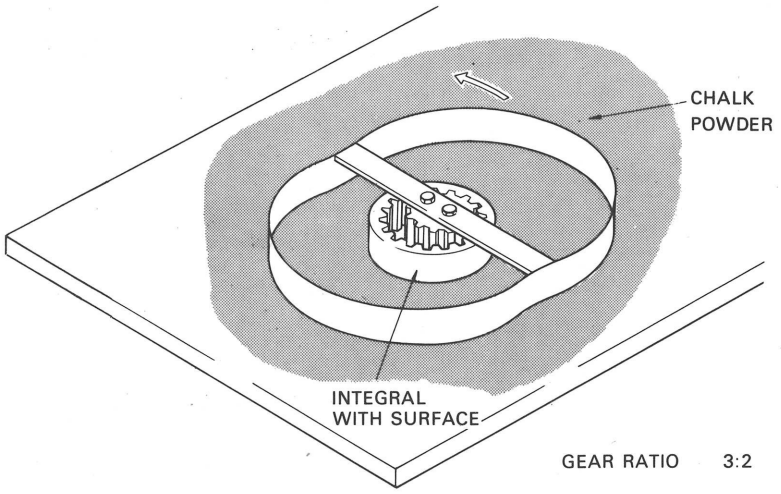


Fig. 11

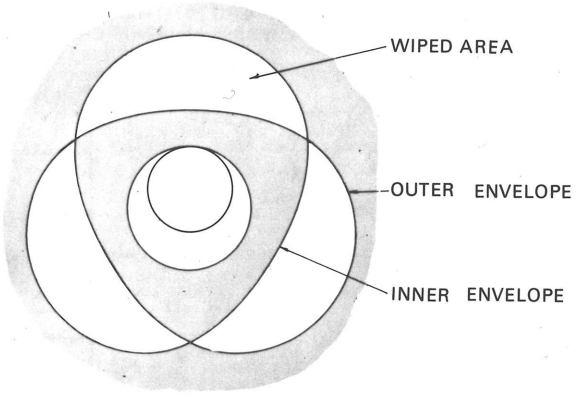


Fig. 12

In Fig. 11, a rigid steel strip loop, bent to present a trochoidal shape, is placed on a surface sprinkled with chalk powder. The cross piece carries, at its center, a pinion, which "walks" around on the internal gear secured to the surface rigidly. The gear ratio of the pinion to the internal gear is 2:3. Remember, the pinion is rigidly secured to the cross piece.

Let the pinion "walk" around along the internal gear teeth in the direction of the arrow. This will swing the steel strip loop, causing it to scrape off the chalk powder. No matter how many times the pinion walks around, the steel strip loop will scrape the same area of the chalked surface, leaving a pattern like the one shown in Fig. 12.

Note, in Fig. 12, that three scraped areas envelop a triangular unscraped area. The three curves (internal enveloping lines), forming a triangle, are the basis on which the contour of the R.E. rotor is generated.

The geometrical relationship between the trochoical loop, determined in Fig. 9 and Fig. 10, and the rotor contour determined as above is a subject beyond the scope of this manual. Let's be sure of one thing here: the shape of the rotor is **not** arbitrarily determined.

1-9. Are there dead centers in the R.E.?

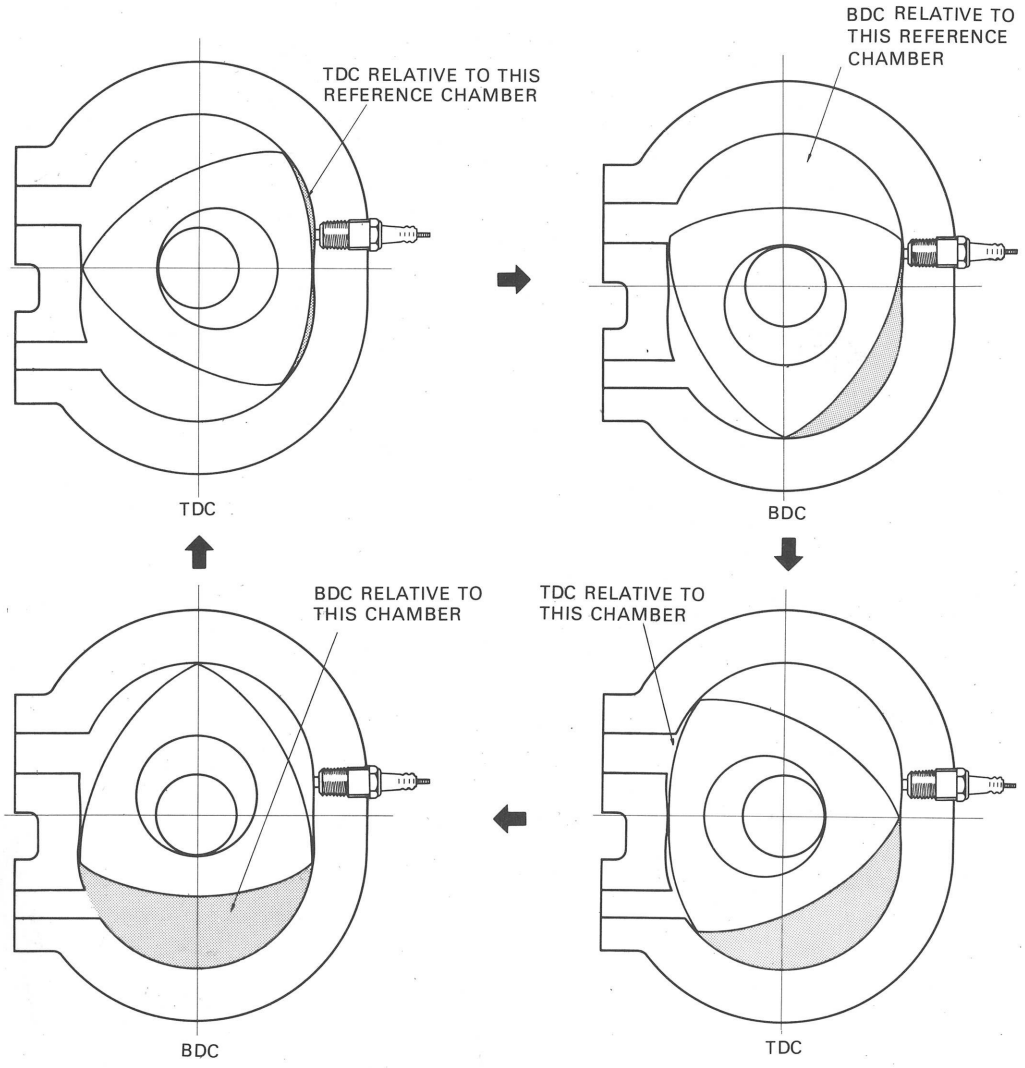


Fig. 13

Yes, but not like those of a reciprocating engine. In a R.E., there is an imaginary arm, which extends in the eccentric shaft bulge through its two centers—center or axis of rotation and geometrical center. This imaginary arm, like the crank arm of a reciprocating engine revolves around the axis of eccentric shaft and is acted on by the push developed by the detonated fuel-air mixture.

Fig. 13 explains how this arm revolves to create the states comparable to the dead centers of the reciprocating machine. When the arm is pointing squarely to the middle point on any of the three rotor sides, the running members (rotor and shaft) are at TOP DEAD CENTER. With the arm pointing to one of the apexes, they are at BOTTOM DEAD CENTER.

Thus, the R.E. may be viewed as possessing two top and two bottom dead centers for one rotation of the eccentric shaft.

1-10. How does the R.E. cycle break down in process analysis?

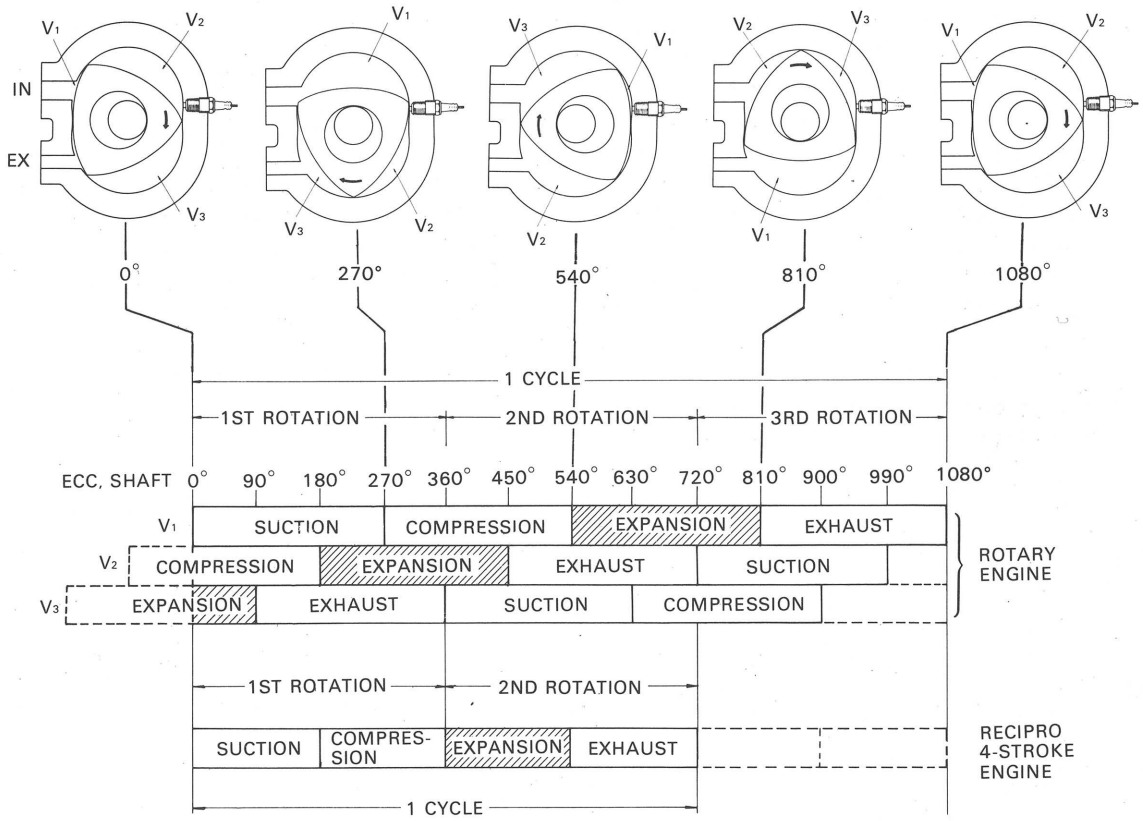


Fig. 14

One rotation of crankshaft completes one cycle of operation in a two-stroke engine; two rotations of crankshaft in a four-stroke engine. In the R.E., three rotations of its eccentric shaft (comparable to crankshaft) brings the rotor back to the original position within the engine. We may say that one R.E. cycle is completed in the interval of 1080° crank angle.

During this 1080° interval, the three chambers V_1, V_2 and V_3 undergo a process of SUCTION, COMPRESSION, EXPANSION and EXHAUST concurrently but not simultaneously: one chamber lags behind another in such a way as to be representable by three staggered bars shown in Fig. 14.

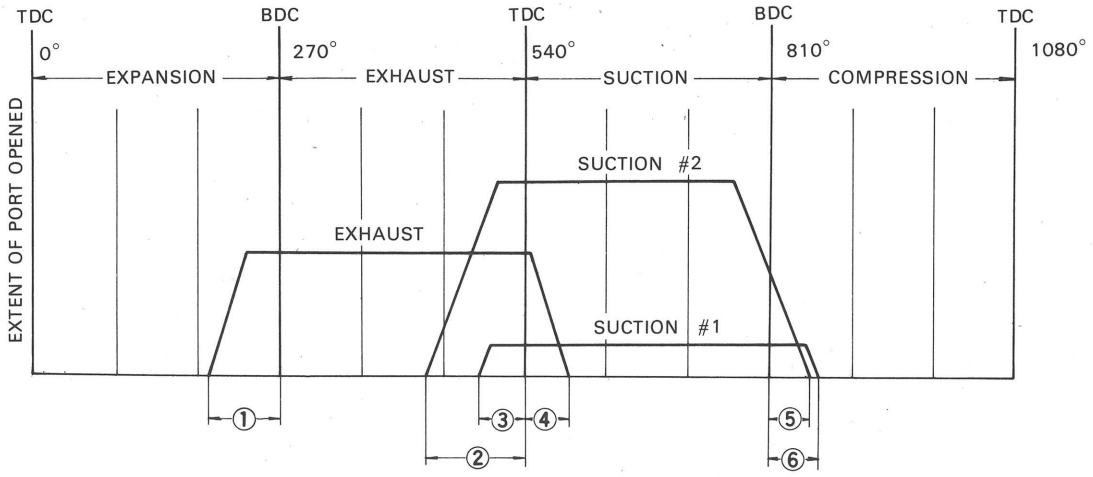
In the diagram of Fig. 14, the "strokes" of each chamber are referred to the angular positions of the eccentric shaft. Note that, in order for one chamber at any instant to occupy the position taken at the same instant by the chamber immediately ahead, the rotor must **rotate** 120° around the eccentric shaft. This 120° is not a crank angle interval; it refers to the position of the rotor in the trochoidal bore. During this interval, the eccentric shaft makes one rotation. It follows, thus, that, in terms of crank angles, any two chambers of the three are 360° crank angle apart (360° eccentric shaft rotation = 120° rotor rotation on that shaft). We speak of V_1, V_2 and V_3 as differing in phase by 360° (crank angle).

In the foregoing backdrop, we shall compare the R.E. and the reciprocating engine with respect to power generation. Since fuel-air mixture explosion occurs once for each rotation of the eccentric shaft, this compares well to a **4-stroke two-cylinder** engine but an important difference is in the totalized interval in which power is transmitted to the output shaft (eccentric shaft in the R.E.). In the **two-cylinder** engine, this interval is 360° long in its 720° cycle, whereas it is 810° long in the R.E., whose cycle is 1080° long.

A very significant conclusion can be drawn here: In the **2-cylinder** engine under consideration, power is available from the output shaft only during its one-half rotation; in the R.E., power availability in the same sense occurs during 3/4 rotation of the output shaft.

2. R.E. DESIGN CONSIDERATIONS

2-1. Port timing



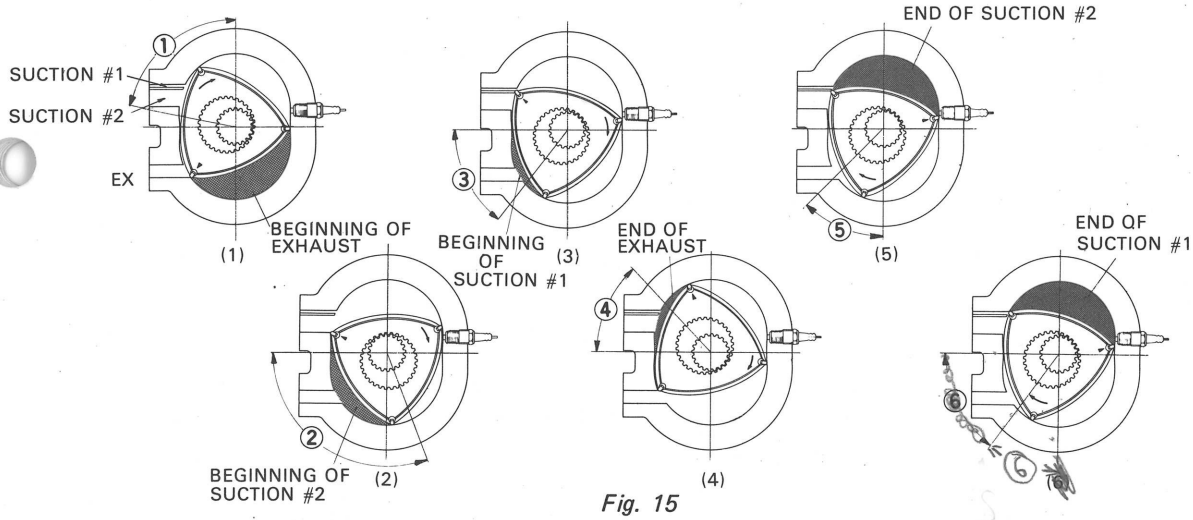


Fig. 15

"Port timing" is an important design consideration for the R.E., just as it is for two-stroke-cycle engines. It refers to the eccentric shaft angles at which the closing and opening actions for the suction and exhaust ports (provided in the rotor housing) take place.

The diagram of Fig. 15 indicates the durations in which these ports remain open.

For the R.E., the beginning of EXHAUST and the end of SUCTION are expressed in terms of the angular position of imaginary "arm" (mentioned in 1-9) relative to the bottom dead center. Similarly, the end of EXHAUST and the beginning of SUCTION are expressed relative to the top dead center. The reader is advised to refer back to the R.E. concepts of top and bottom dead centers explained in 1-9.

In the timing diagram of Fig. 15, it should be noted that, during the transition from state (2) to state (4), EXHAUST and SUCTION are partially overlapped for the reference chamber (shaded).

2-2. Displacement and compression ratio

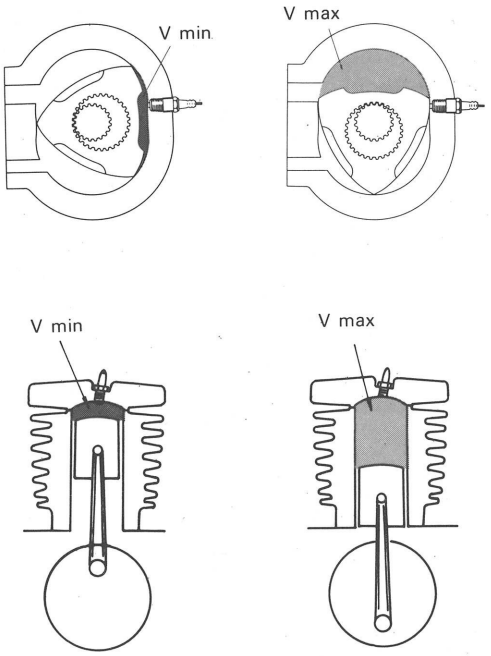


Fig. 16

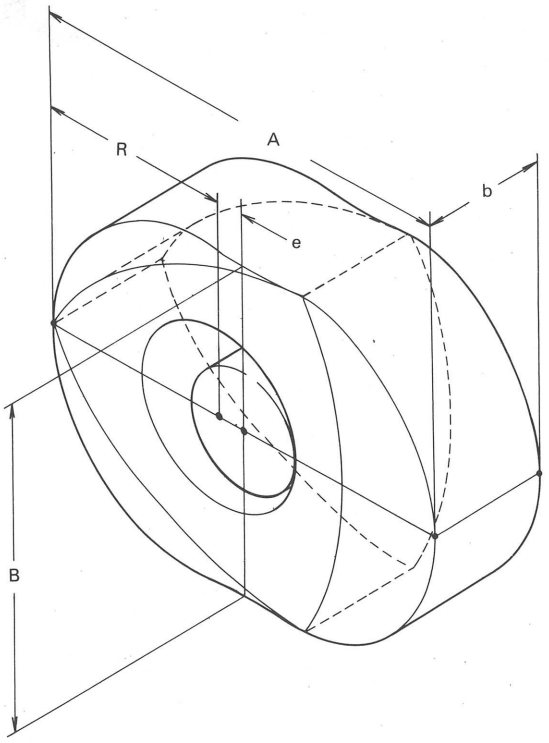


Fig. 17

The R.E. takes up the same notions as are used in reciprocating engines for the expression of capacity or displacement and compression ratio.

$$\text{Displacement} = V_{max} - V_{min}$$

$$\text{Compression ratio} = \frac{V_{max}}{V_{min}}$$

Actual displacement is computed on the basis of the dimensions shown in Fig. 17 and by inserting the values into either of the following two formulas:

$$\text{Displacement} = 3\sqrt{3} \cdot e \cdot R \cdot b \fallingdotseq 5.196 \cdot e \cdot R \cdot b \text{ , or}$$

$$= \frac{3\sqrt{3}}{16}(A^2 - B^2) \cdot b \fallingdotseq 0.325\,(A^2 - B^2) \cdot b \text{ ,}$$

where: A = major axis,
B = minor axis,
R = generating radius,
e = eccentricity, and
b = rotor width.

2-3. Ratio of generating radius (R) to eccentricity (e)

The value of R/e is called the trochoid constant. It is the starting point of R.E. engineering, and is equivalent to the "bore × stroke" of the reciprocating engine. The characteristics and dimensions of a R.E. are determined largely by the trochoid constant.

There are many rotary engines being developed or being commercially manufactured today. They may appear similar in profile but **are not.** The R.E. can take various shapes looking alike but differing in shape details, let alone different sizes, all depending on the value of the constant R/e. This is illustrated in Fig. 18.

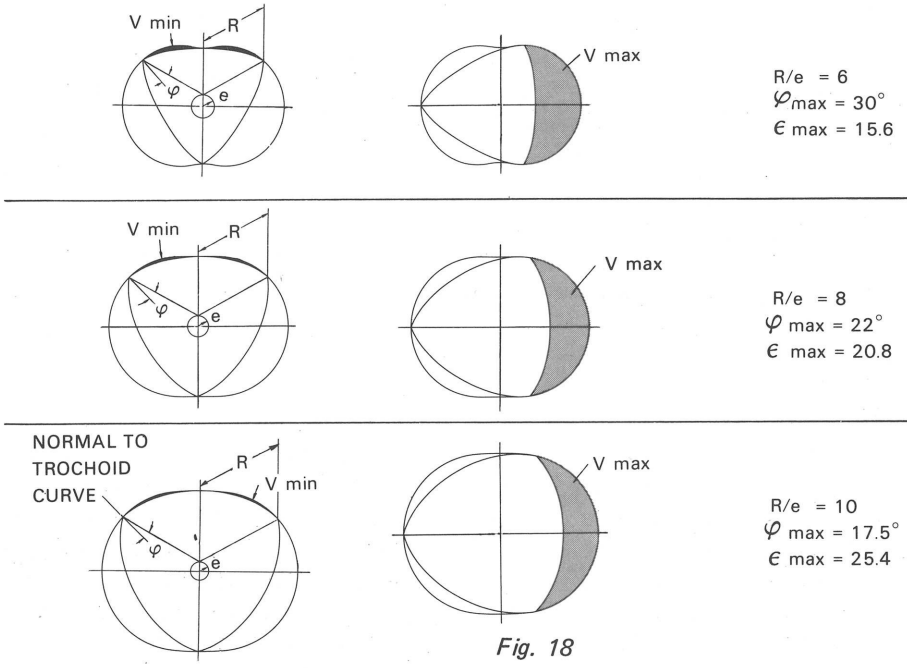


Fig. 18

For a given product of "e × R" (which may be construed to mean a given engine capacity), the designer has some latitude in selecting the constant R/e for realizing the given capacity. Let the constant R/e change its value in three steps; first, R/e = 6, then R/e = 8 and lastly R/e = 10. Fig. 18 shows three configurations based on these three values of R/e.

The larger the value of R/e, the larger and rounder the profile of the bore. If you reduce the value of R/e, then the profile approaches that of a peanut pod, with increasingly pronounced inward bulges at the two sides.

Another important factor of R.E. designing is φmax, which is called the maximum **rocking angle.** The adjective "rocking" is used for conveniences; it refers to the angle included between the line normal to the trochoid and the pointing direction of the rotor apex. This angle varies under the running condition of the rotor, as if the apex rock to and fro on the trochoical surface of the bore. A smaller value of φmax calls for a larger value of "R" (and hence an engine larger in physical size) or a smaller value of "e" (and hence a smaller torque-developing leverage). The designer has to optimize these factors in working out a practical design.

The largest possible compression ratio — theoretically possible — is represented by ϵ max. The larger the trochoid constant R/e, the larger the ratio. For an actual R.E., its compression ratio is roughly determined by two factors, the R/e and the required volume of the recess in each rotor face opposite the bore wall.

2-4. Bore profile modification by trochoid displacement

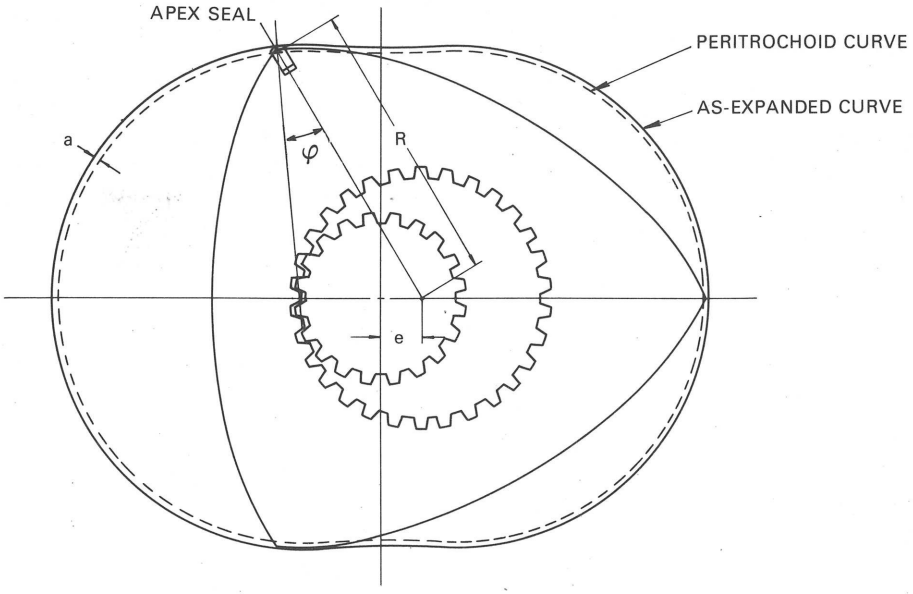


Fig. 19

The techniques of generating a peritrochoid or epitrochoid, outlined in 1-7, are theoretical. In actual practice, a peritrochoid loop is first generated on the basis of the design parameters, and is then expanded slightly by displacing each point of the original peritrochoid curve along its normal line. In Fig. 19, the amount of expansion is indicated as "a", the expanded loop is shown in solid line, and the original trochoid in dot line. The significance of "a" will be clarified.

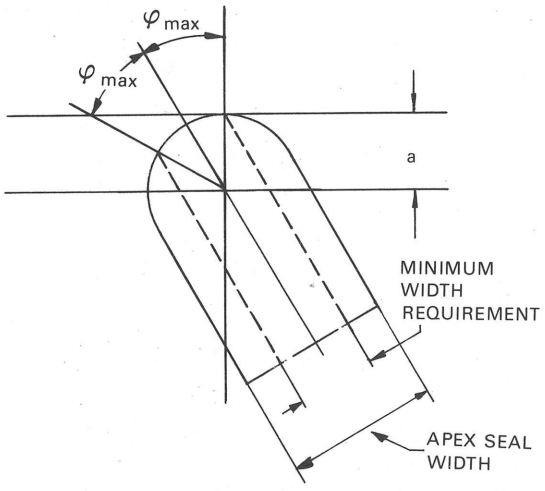


Fig. 20

A seal strip is fitted in each apex of the rotor. See Fig. 20. Since the apex is forced to rock, as stated previously, the sliding point of the seal strip must be round in such a way as to cope with the varying rocking angle φ. Without this provision, the apex seal strip would be rubbing by the same localized tip and, obviously, that is hard on the strip. This condition would then result in localized heat generation and premature wear.

These undesirable effects are avoided by rounding the seal strip point with a radius of the rocking motion, as shown in Fig. 20. The amount of expansion, mentioned above, is equal to this radius in value.

The rocking motion has a certain amplitude, and the thickness of the seal strip must be wide enough at least to cover that amplitude. The larger the rocking angle φ or the amount of expansion "a", the larger must be the thickness of the strip. The maximum thickness that an apex seal of the shape shown takes is twice the value "a" (2a) on the condition that the seal strip will not move up and down in the slot provided in the apex.

3. CONSTRUCTION FEATURES OF THE R.E.

3-1. Gas seals

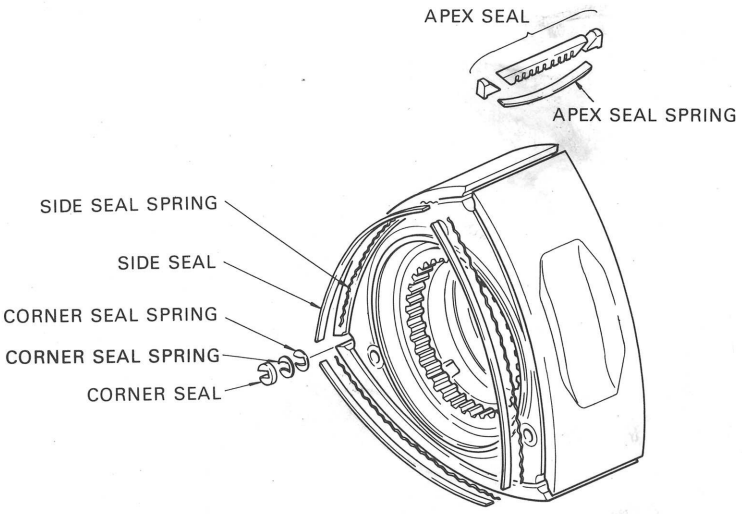


Fig. 21

The various gas seals are identified in Fig. 21. They isolate one chamber from another to contain the detonated fuel-air mixture in one chamber and the compressed mixture in the subsequent chamber while preventing these high pressures from leaking into the chamber at negative pressure for drawing in a fresh supply of fuel-air mixture.

3-1-1. Sealing faces

People are not few who think that a piston ring seals against the high pressure up above by its sliding face alone. That's wrong. The fit of the ring in its groove has a lot to do with the sealing action. In the same way, the principal sealing action is accomplished in the R.E. by those sliding faces of the apex seal (sliding along the bore wall) and the side seal (sliding on the flat wall of the side housing), but those concealed faces in contact too play an equally important part.

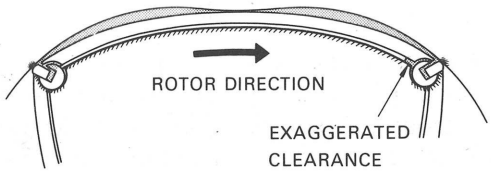


Fig. 22

Fig. 22 shows a state comparable to the top dead center on compression stroke in the reciprocating engine. The faces taking part in containing the high pressure are indicated by bristled lines. It should be noted that, if these sealing members were ideally situated, if there were no clearance between each end of the side seal and the corner seal next to it, there would be no leakage. As will be noted in Fig. 22, which applies to an actual R.E., the importance of that clearance in particular can never be overemphasized.

3-1-2. More about the apex seal

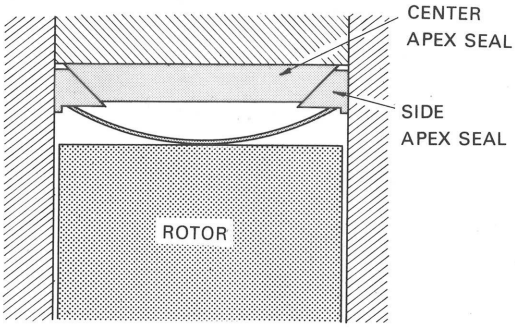


Fig. 23

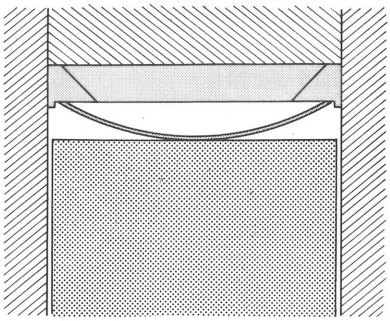


Fig. 24

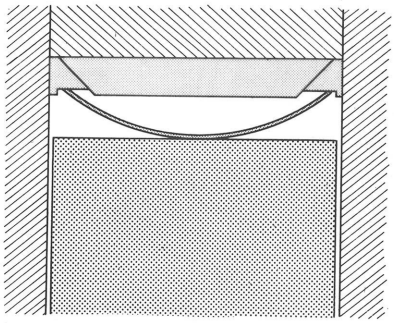


Fig. 25

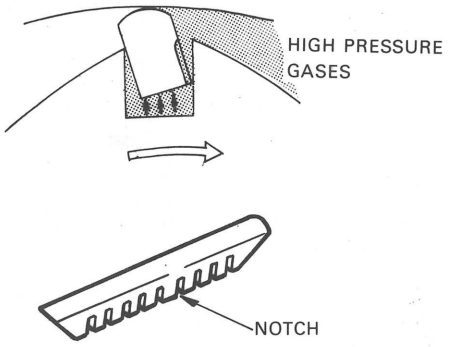


Fig. 26

The apex seal is called upon not only to perform its sealing action at the bore wall but also to cooperate with the corner seals in doing the same at the flat wall of each side housing. In the present R.E., the apex seal strip is in three pieces held together, with an angled joint between two abutting pieces, and is backed by a spring, which presses the center strip and two side strips against the bore wall and pushes the two side strips sideways against the walls of the side housings, right and left.

Fig. 23 shows the condition of the apex seal sub-assembly in a new engine. Note that the side seal strips are slightly longer, so that they are not quite in contact with the bore wall. These two pieces are of a material slightly less hard to wear than that of the center piece, and are calculated to wear in time to assume the condition shown in Fig. 24. By the time the apex seal has changed its condition to what is shown in Fig. 24, the vehicle powered by this engine will have covered a long mileage. From this point onward, the seal approaches the condition shown in Fig. 25.

The side seal strips wear faster than the center one. Since they are urged by the backing spring and, moreover, their mating faces with the center strip are sloped, they will keep on fitting snugly to the corners, preventing the overall length of the apex seal sub-assembly from getting shorter. This is a self-compensating action.

An additional feature on the center strip is a few notches provided on its leading side. This feature includes a minor rattle given to the center strip. When that condition occurs, the pressure of compression or explosion cocks the strip but the notches admit the pressure into the bottom side, thus augmenting the force of the backing spring to press the strip against the bore wall and thereby preventing the center strip from getting stuck in cocked position.

3-2. Oil seals

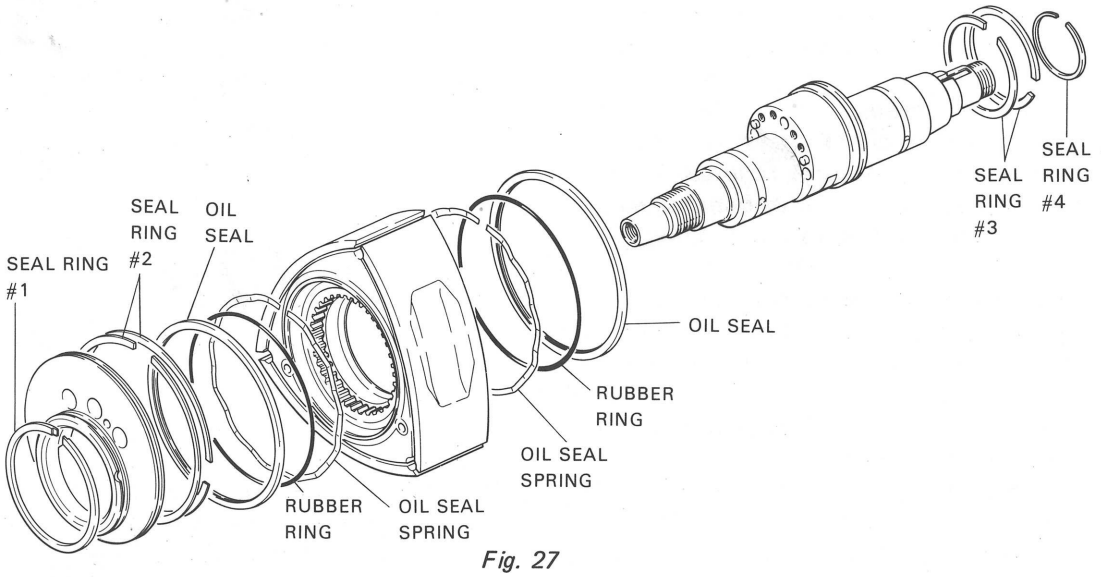


Fig. 27

Oil seals are identified in Fig. 27. They perform the function similar to that of the oil rings fitted to pistons in the reciprocating engine. They are to prevent the lubricating oil from finding its way toward the chambers, particularly to the chamber in which suction is taking place, and do so at the walls of the side housings.

As the first line of defense, there are provided four sealing rings, numbered 1, 2, 3 and 4 in Fig. 27. These rings contains the oil which cools the rotor and lubricates the bearings supporting the concentric portions of the eccentric shaft. Oil leaking past these rings is but small in quantity. This leakage, getting into the sliding clearances between rotor and side walls, meets the oil seals acting as the second line of defense.

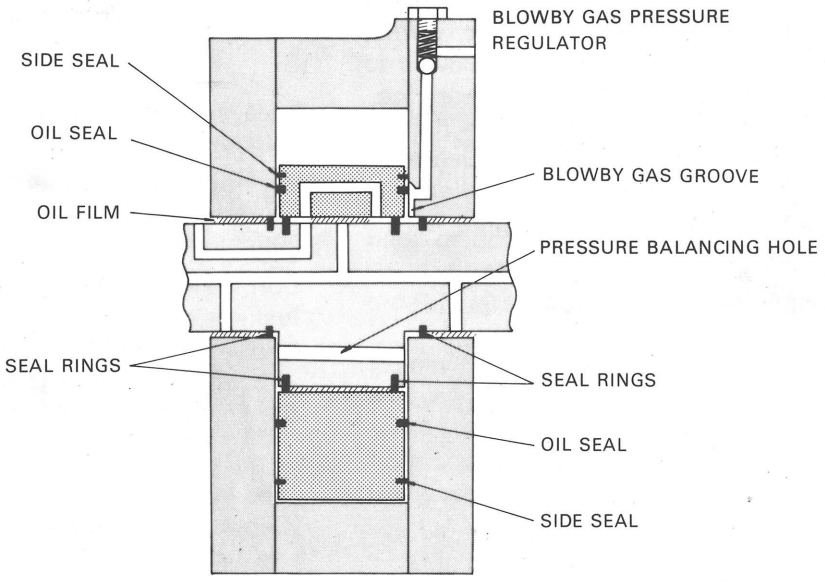


Fig. 28

The cross section of Fig. 28 depicts the oil sealing arrangement schematically. Note that a groove is provided, extending from the bore, on the inner wall of the side housing (right). This groove is communicated through an internal, drilled passage to a check valve (named the blowby gas pressure regulator). The relieving port of this valve communicates to a device external to the engine.

As to the length and location of this blowby bleeding groove, it should be recalled that the oil seal on each side of the rotor rubs a certain circular areas of the side wall of the housing. This is because the rotor is flung around (revolving), the while it rotates. Should the rotor merely rotate, then the seal would rub along a circular line, not area. The circular area rubbed by the oil seal is due to the complex motion of the rotor.

The groove is so extended and oriented that its outer end "peeps" into the clearance beyond the oil seal **only when the rotor comes to a certain angular position.** When this occurs, the blowby gas (the gas that has leaked out past the side seals and corner seals) finds its way out toward the built-in valve (regulator).

The regulator bleeds off the blowby gas only when the gas pressure exceeds a predetermined level. In other words, some blowby gas pressure is allowed to exist at all times in the sliding clearance. The clearance on the other side (left) is communicated to the right-side clearance through a balancing hole drilled out through the width of the bulge of the eccentric shaft.

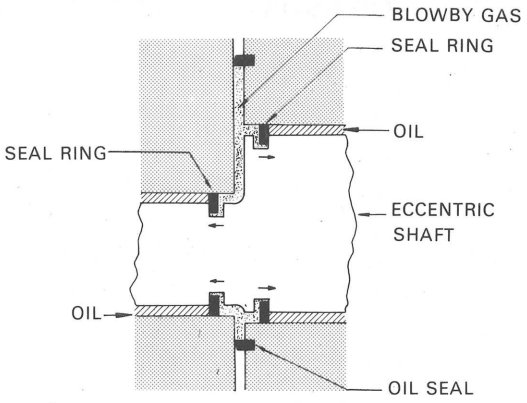


Fig. 29

The effects of the controlled blowby gas pressure present in the sliding clearance are visualized in Fig. 29. This pressure acts on the oil seal rings favorably; it pushes each ring against the shoulder to minimize the leakage.

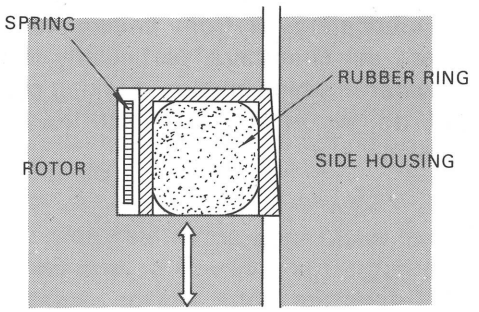


Fig. 30

Fig. 30 shows the oil seal in section to reveal the details of its construction. Its sliding face is tapered for oil scraping action. The rubber ring stems off the leakage oil seeking to find its way outward through the back of the seal where a wavy circular leaf spring is provided to press the seal against the side wall.

3-3. Lubrication system

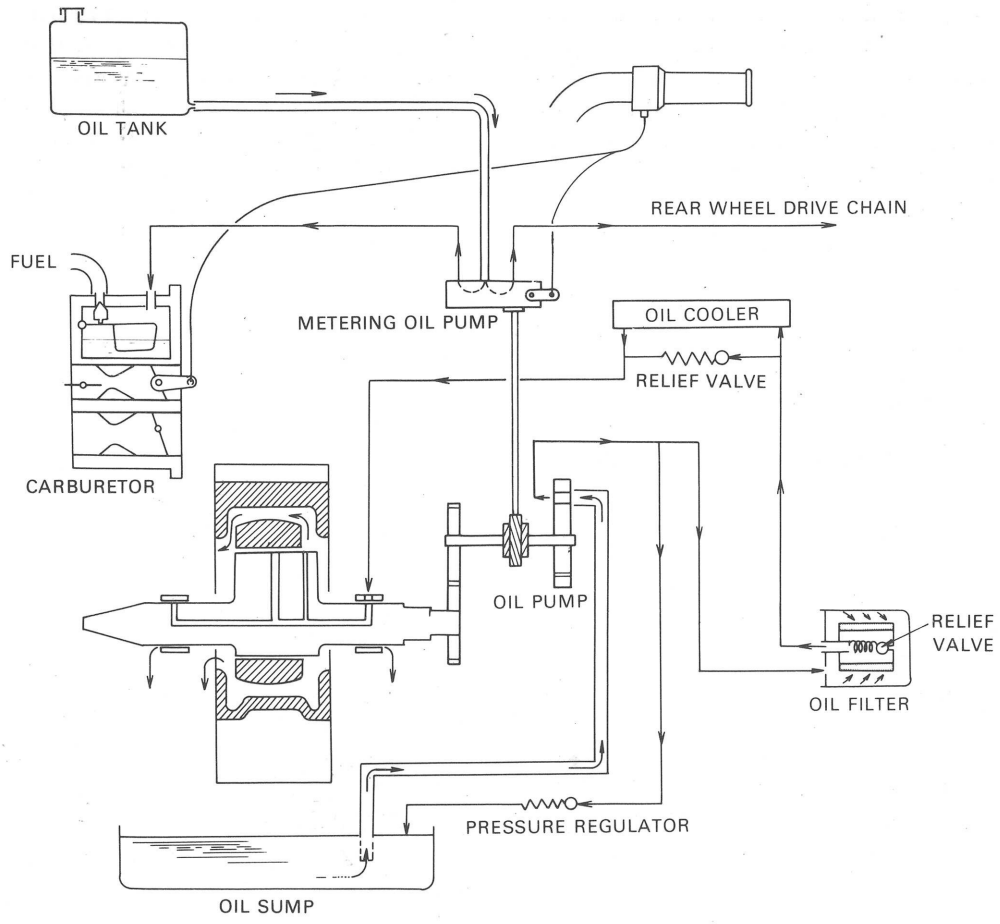


Fig. 31

Referring to the engine lubrication system diagram, the oil pump lifts oil in the engine oil sump and delivers it against pressure through the oil filter. From this filter, the oil proceeds through the cooler and enters the R.E. proper.

As the engine picks up speed in operation, the oil pressure in the pump discharge line rises. In order to limit this pressure rise, a pressure regulator is installed between pump and filter. The oil bled out by the regulator flows right back to the oil sump. During normal operation, the engine is supplied with lube oil at a constant pressure.

Oil filter and cooler are each equipped with a relief valve. In the event of a clogged filter or cooler, the relief valve operates to allow the oil to bypass the filter or cooler. This feature assures the uninterrupted supply of lube oil to protect the R.E. against such an unlikely situation.

Within the engine, the oil lubricates the running fit of the rotor on the eccentric shaft and also the rotor rotating gears; it lubricates also the bearings of the eccentric shaft.

The gas seals—apex seals, corner seals and side seals—too need lubrication because they are in sliding contact. This requirement is met by injecting lube oil into the carburetor; the oil comes from another oil tank and is fed to the carburetor by a metering oil pump. This lubrication scheme constitutes an independent system distinct from the main system described above.

In the carburetor, the oil mixes with the fuel and is carried by the fuel-air mixture into the intake port. The metering oil pump is associated with throttle control and delivers oil in proportion to the throttle position. When the engine is in full-load operation, the throttle valve will be wide open and the metering oil pump will be delivering at a full rate to meet the requirement for the gas seals.

3-4. Engine cooling

3-4-1. Internal cooling of the engine

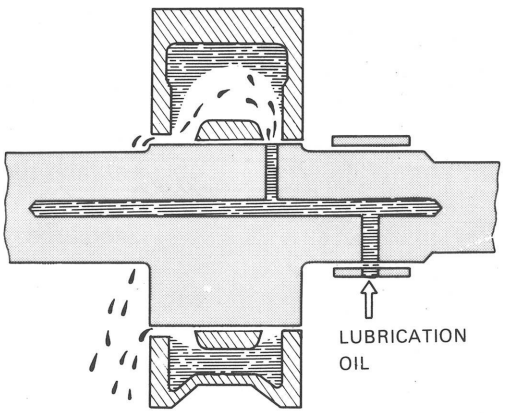


Fig. 32

Heat tends to build up inside the piston in the reciprocating engine. If the engine is of 4-stroke-cycle type, this heat is usually removed by spraying lube oil into the pocket around the pin. In a 2-stroke-cycle engine, the fuel-air mixture cools that portion of the piston. For the same reason, the R.E. rotor must be internally cooled to curb down the build-up of heat inside.

Fig. 32 shows how this is accomplished. Note that part of the lube oil supplied under pressure for engine lubrication is diverted and led into the cavity formed inside the rotor. The oil flowing out of the rotor is hot. This oil merges with the oil that has lubricated the various parts and returns to the oil sump, from which it is pumped out and forced through the oil cooler.

3-4-2. Rotor-housing and side-housing cooling

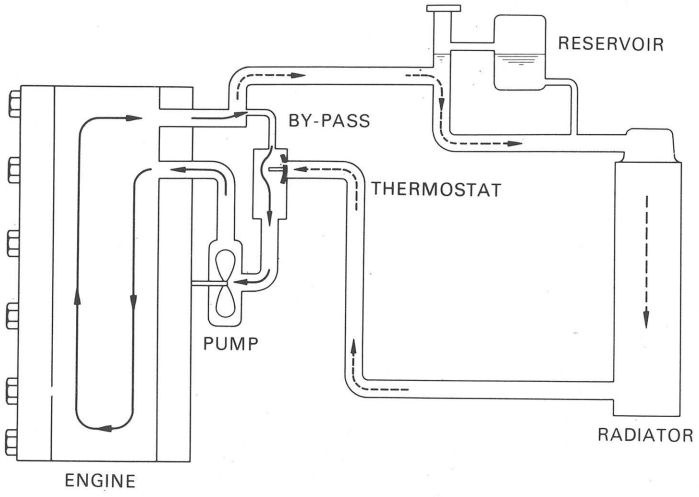


Fig. 33 Thermostat closed

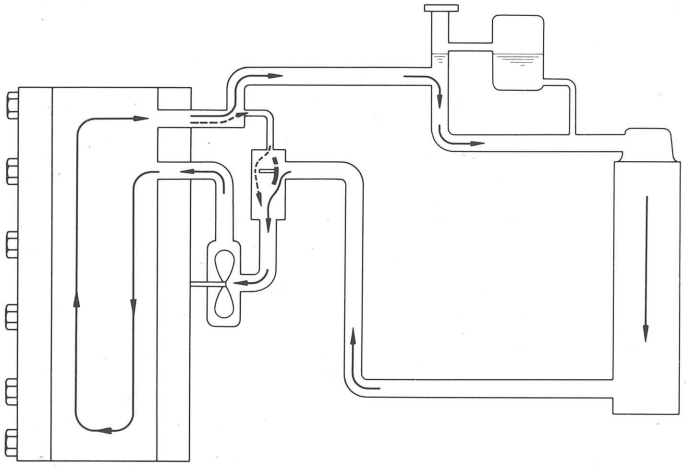


Fig. 34 Thermostat opened

In the absence of industry-wide established nomenclatures for the three parts enclosing the rotor, we use the terms "rotor housing" and "side housing" to designate these parts. The housings are cooled by circulating water, which is set in motion by a water pump in the circuit outlined in Figs. 33 and 34.

The thermostat is closed in Fig. 33. Water recirculates through the route comprising pump, engine and bypass passage, after which comes the pump again to complete the loop. Under this condition, the engine is heating the water and a small water flow exists through the radiator to introduce cold water to the back of the thermostat valve. This flow is due to an orifice provided in the valve, and is calculated to avoid an inrush of cold water from the front to the temperature sensing part of the valve when it opens. Fig. 34 shows the thermostat valve unseated to cut in the radiator: the water flows now from pump through engine, radiator and thermostat and back to the pump. The bypass passage serves, under this condition, to bleed out air bubbles that may have developed in the circuit.

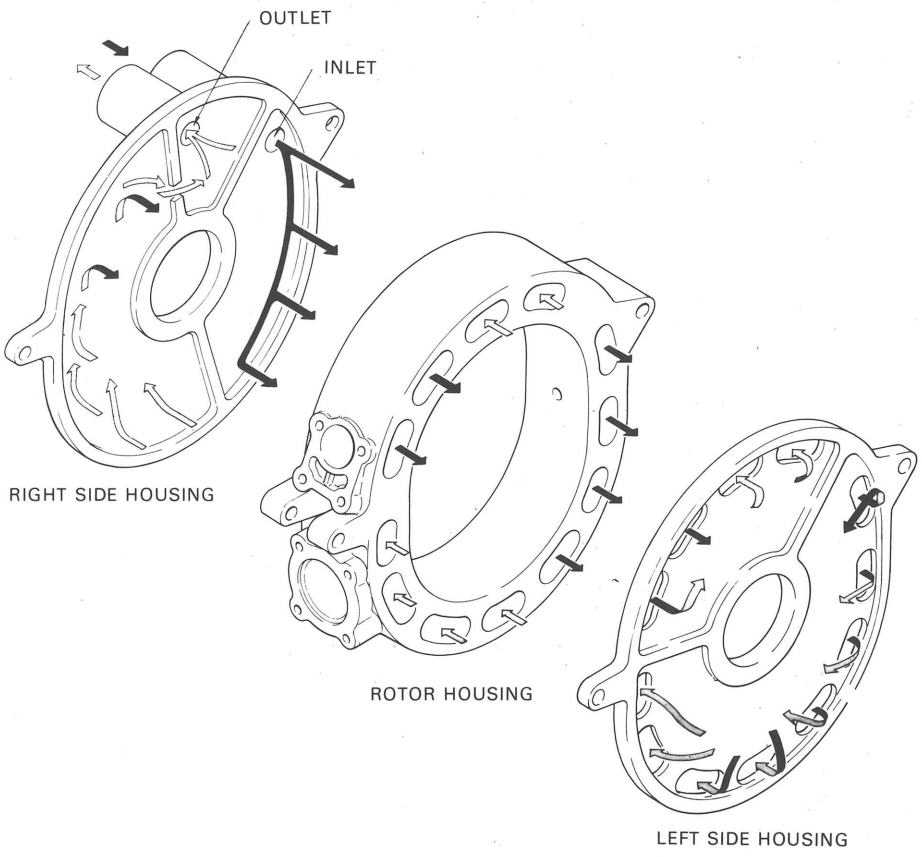


Fig. 35

The paths of water flow through the jackets provided in the housings are illustrated in Fig. 35. We shall trace this flow, starting with the inlet port provided in the right-side housing. From the inlet, water flows past the hot region where combustion takes place in the rotor housing and, upon entering the left-side housing, makes an aboutface for re-entry into the rotor housing. Water then flows past the region of the exhaust port and returns to the right-side housing. By this time the water is hot. The hot water then encounters a partition having a notch. Part of the water flows through this notch and finds its way out through the outlet port while the remainder is deflected to make a round trip once more through the rotor and left-side housings before reaching the outlet port. This round trip is through the cold region where the fuel-air mixture is drawn into the rotor housing. Thus, the hot water flowing slowly (because it is the remainder) in this region gives out its heat to the housings there to minimize temperature differentials through the mass of the housings, thereby reducing the thermal distortion.

3-5. Gas venting system

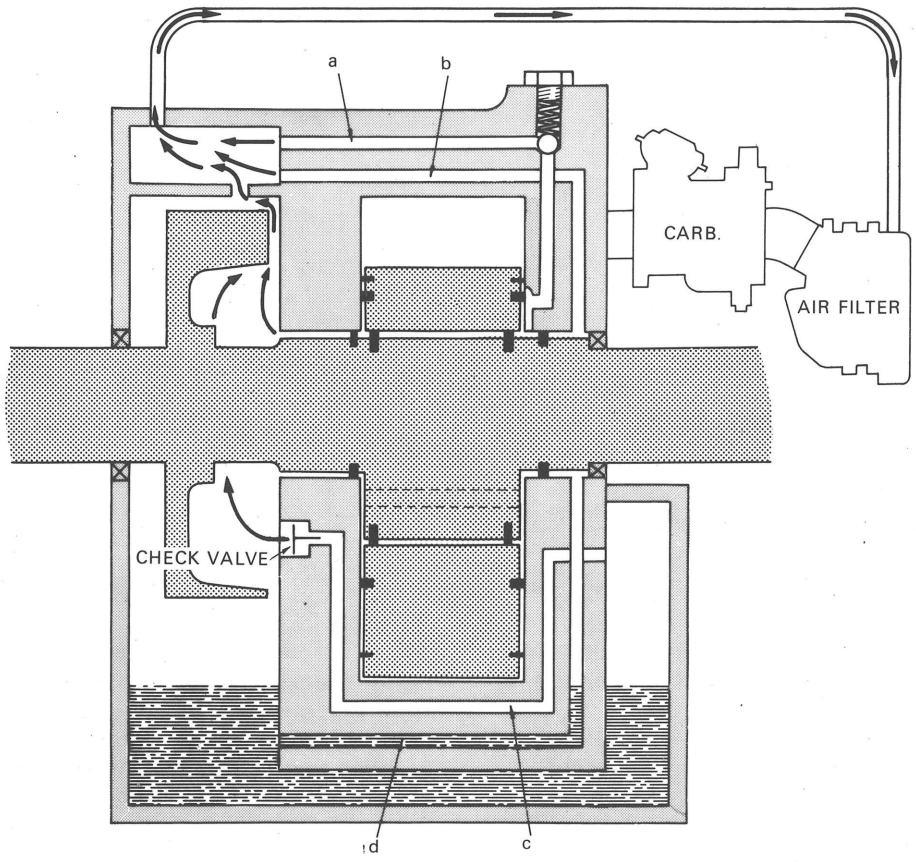


Fig. 36

It was stated in 3-2 that the blowby gas bled out by the blowby gas pressure regulator is forwarded to a device external to the engine proper. That device is the air filter. The bled-out gas is guided to the external circuit through the passage "a" provided in the housings, as shown in Fig. 36, to which the following description refers.

Passage "b" is for ushering the blowby gas (leaking from the bearing part in the right-side housing) to the same external circuit. Passage "c" passes the gas (collecting in the right-side air space above the oil sump) to the left side.

At the outlet opening of passage "c" is provided a check valve in order to prevent reverse flow of air through this passage. Without this check valve, oil level on the right side might fall so low as to allow the oil pump to draw in air, as when the engine is started in the motorcycle leaning on its prop stand (which is on the left side). In such a tilted condition of the engine, the check valve may not be tightly seated at first but will seat firmly as soon as the pump starts drawing out the oil there to lower the level. The level may fall slightly but the resultant vacuum prevents a further drop of oil level in the right-side sump.

Passage "d" has no direct bearing on the gas venting system. This passage guides to the oil sump the excess lube oil leaking from the right-side bearing part. This oil is expected to carry more or less bubbles due to leakage blowby gas. This is the reason why the oil is led to the left side so that the bubbles will not be drawn into the oil pump.

4. CARBURETOR

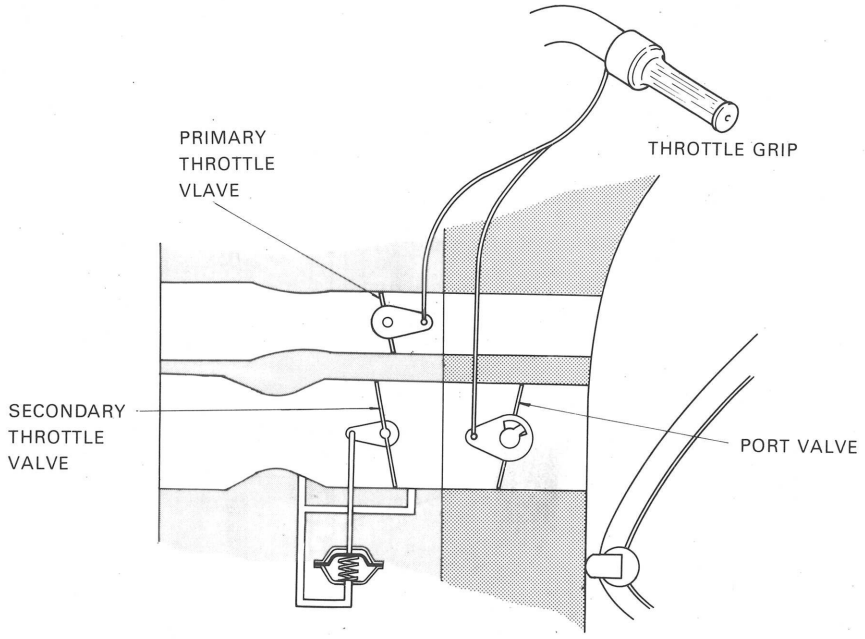


Fig. 37

The carburetor used on the present R.E. is of two-barrel two-stage type, in which the primary bore and the secondary bore are communicated to the engine inlet port through their own separate paths, independent from each other, as will be noted in the schematic of Fig. 37.

The primary throttle valve is actuated from the throttle grip, whereas the secondary throttle valve opens and closes depending on the vacuum present in the secondary bore. In addition to these valves, a third valve, called the port valve, is provided in the inlet port formed in the rotor housing. This third valve too is actuated from the throttle grip, but the control cable is so set that the port valve begins to open when the primary throttle valve has opened by a predetermined amount.

It will be seen that vacuum in the secondary bore is a function of two variables: the position of the port valve and the rotating speed of the engine. It follows, therefore, that the position of the secondary throttle valve is determined mainly by these two variables. More will be said later about this valve regarding its movement.

The real object of the port valve is to isolate the space in the inlet port from the chamber that has shifted to the inlet region of the bore wall. This isolation is desired only when the primary valve is in "partial throttle" position (meaning a small amount of fuel-air mixture being drawn into the SUCTION chamber being formed toward the end of the EXHAUST action). There is some overlap of two states, EXHAUST and SUCTION, during the transition from one to the other in the same chamber. Some exhaust gases will inevitably flow into the SUCTION-state chamber and, if the port valve is absent, into the inlet port. This would "thin" the fuel-air mixture.

In short, the port valve serves to minimize the inlet port space communicating to the SUCTION-state chamber and thereby suppress the dilution of the mixture by the exhaust gases.

4-1. Choke system

4-1-1. FAST IDLE mechanism

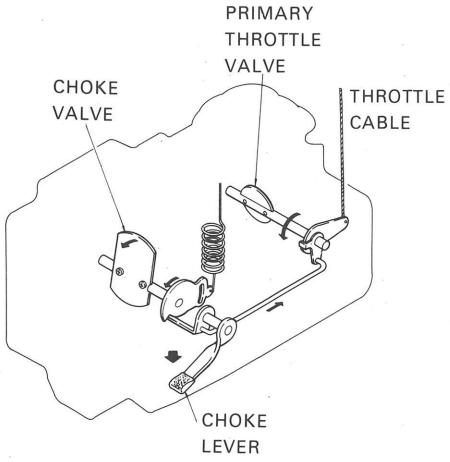


Fig. 38

Pressing down the choke lever closes the choke valve to block the passage of air into the primary bore, causing the main nozzle to spray out fuel more profusely. To facilitate this spray, the primary throttle valve needs to be opened slightly more than when the engine is "idling" low in hot condition. This requirement is met by interconnecting the two valves in such a way that the choke valve being closed will actuate the primary throttle valve in opening direction. The scheme is illustrated in Fig. 38; it prevents a cold engine just started up from stalling due to poor fuel combustion conditions.

4-1-2. Choke unloader mechanism

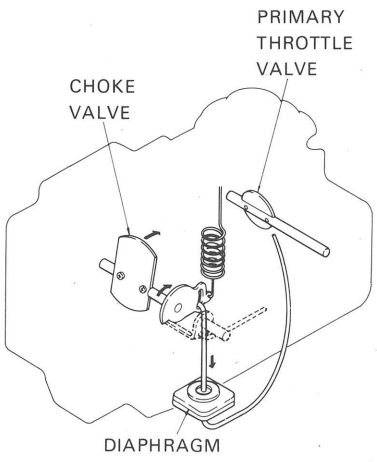


Fig. 39

The diaphragm-actuated automatic choke unloader mechanism is illustrated in Fig. 39.

Starting up a cold engine by choking means a supply of enriched fuel-air mixture for facilitating the firing up action in the engine. After the engine has been so started up, with the choke valve closed, its running condition will become steady. Since the rotor is rotating faster, the vacuum in the carburetor is greater and hence the mixture becomes richer. Then, the choke valve must be opened just a little to reduce the vacuum. This need is satisfied automatically by the diaphragm.

4-2. Accelerating pump

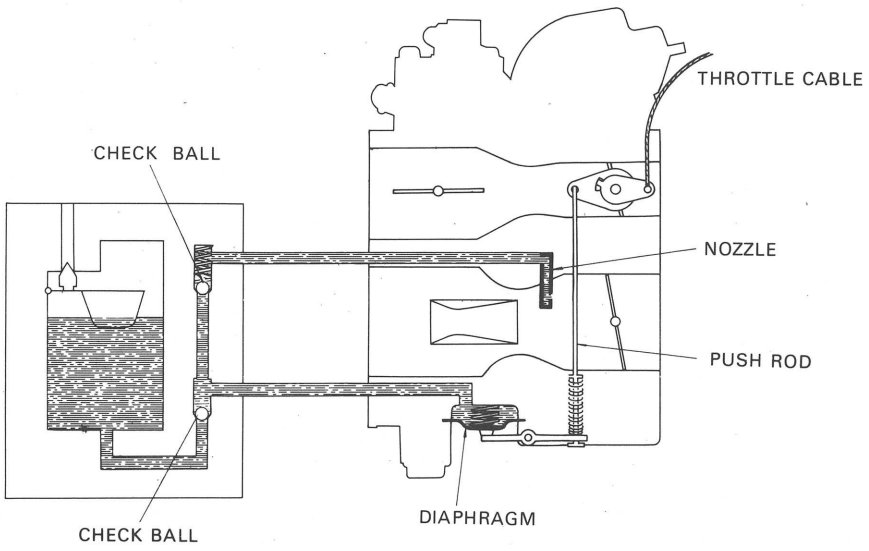


Fig. 40

During acceleration, the increasing supply of fuel tends to lag behind the increasing supply of intake air in the carburetor because fuel is heavier than air. Because of this tendency, the mixture would become leaner to prevent the motorcycle from picking up speed as fast as is desired, were it not for the accelerating pump provided in the manner shown in Fig. 40.

The pump is of diaphragm type; it is actuated from the throttle grip by way of the primary throttle valve and a linkage consisting mainly of a pushrod. As the grip is twisted, the pump becomes actuated instantly to inject additional fuel into the secondary bore to meet the sudden rise in fuel requirement.

The fuel-filled space above the pump diaphragm is below the fuel level in the float chamber, so that it is always kept filled through the circuit in which a check valve is provided.

Since the diaphragm is urged downward by the spring, the diaphragm tends to back down the moment the throttle grip is twisted back. When this occurs, the spring-loaded check valve closes to interrupt the enriching supply of fuel and the other check valve opens to admit fuel into the pump, allowing the diaphragm to go down.

At the throttle valve where the control cable is linked to the pushrod, a play is provided to delay the transmission of cable movement to the pushrod. The spray orifices of the nozzle are oriented for improved spraying.

4-3. Positive bias circuit

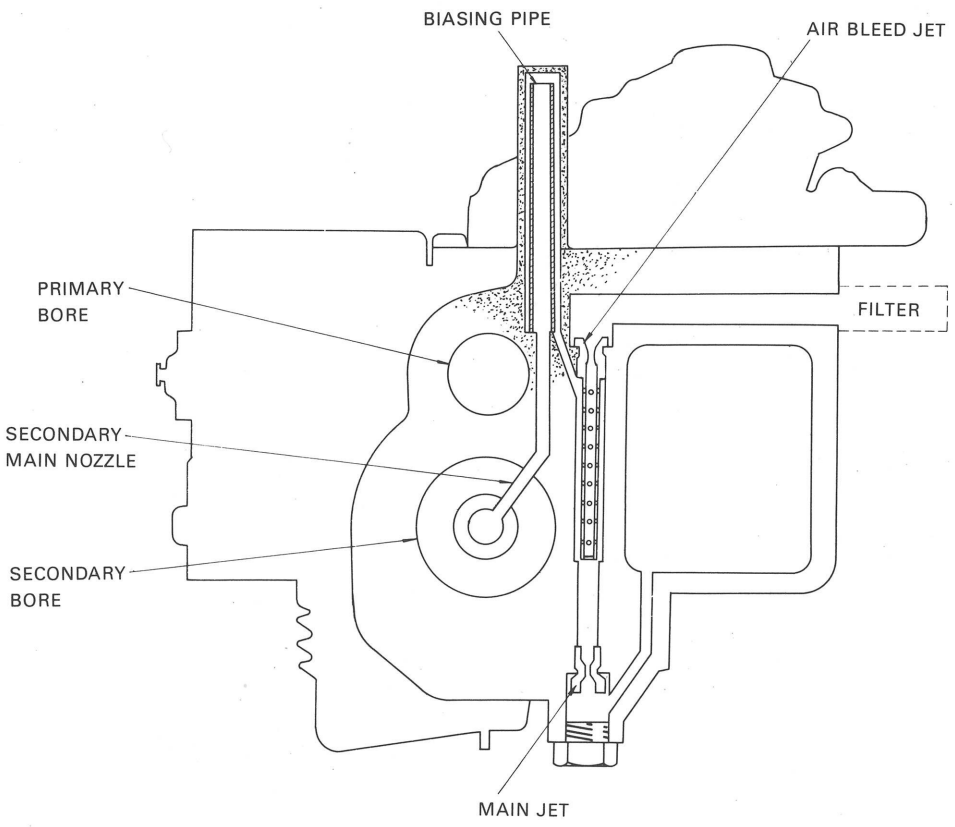


Fig. 41

The relationship between float chamber and secondary-bore main nozzle is schematically shown in Fig. 41, wherein the secondary bore extends toward the reader. The path of fuel is from the float chamber through the main jet, the well in which the air bleed tube is located, the biasing pipe, and to the main nozzle. The vacuum at the main nozzle must be large enough to overcome the head represented by the height of the bias pipe above the surface of fuel in the float chamber. A small vacuum in the secondary bore is unable to cause the main nozzle to spray out fuel.

The reason why the bias pipe is provided is as follows: When the secondary throttle valve is in closed position, there could not be vacuum in the secondary bore; but this is not so, actually, and the main nozzle is subjected to some vacuum—a very small vacuum—due to the vacuum condition of the primary side because, at the air inlet side of the carburetor, the secondary and the primary bore are communicated to each other.

The bias tube introduces a head which is large enough to prevent fuel from trickling to the secondary-bore main nozzle when this nozzle is supposed to be out of fuel spraying action.

4-4. Secondary throttle valve actuating mechanism

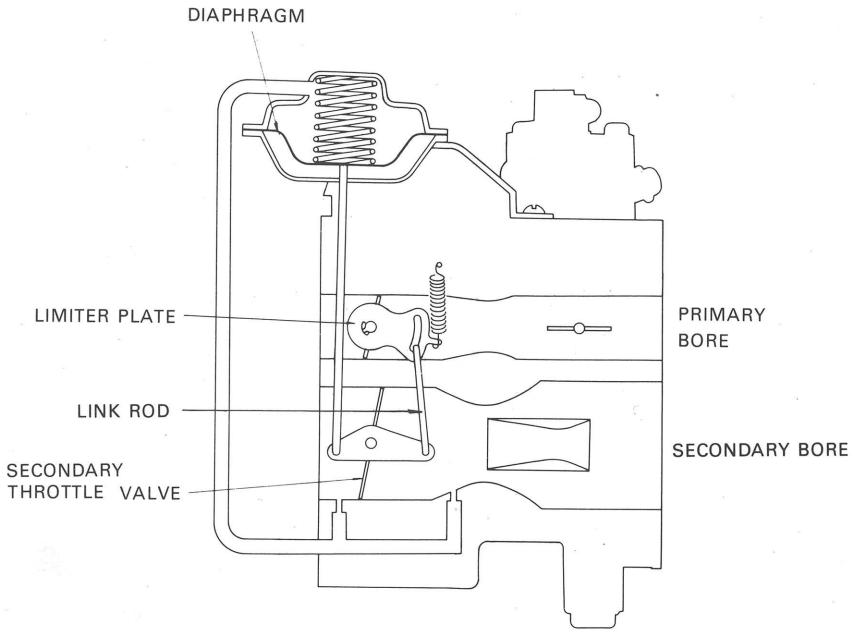


Fig. 42

The secondary throttle valve is actuated by the diaphragm motor operating with vacuum present at this valve in the secondary bore. In the condition shown in Fig. 42, the valve is unable to open because its movement in opening direction is blocked by the link rod and limiter plate. The force for pulling the diaphragm against its spring is developed by the vacuum existing at two places, one on the upstream side and the other on the downstream side of the valve.

Now, let's shift our attention to the connection between the shaft of the primary throttle valve and the limiter plate. The shaft is obviously capable of turning the limiter plate, and starts turning it when its lug (formed on the shaft end) comes to the other end of the slot. If the primary throttle valve is opened by a large amount, the limiter plate changes its position to allow the link rod to move down until it meets the end of the arc slot provided in the plate. And, if that happens, the diaphragm may or may not turn the secondary throttle valve all the way in opening direction, depending on the condition of the vacuum in the secondary bore. Should the primary throttle valve open further, then the extent through which the secondary valve is permitted to open would increase.

Thus, it may be summarized that the maximum open position of the secondary throttle valve is limited by the current position of the primary throttle valve, and that the secondary valve is controlled by the vacuum in the secondary bore to open more or less within the range so limited.

4-5. Enrichment device

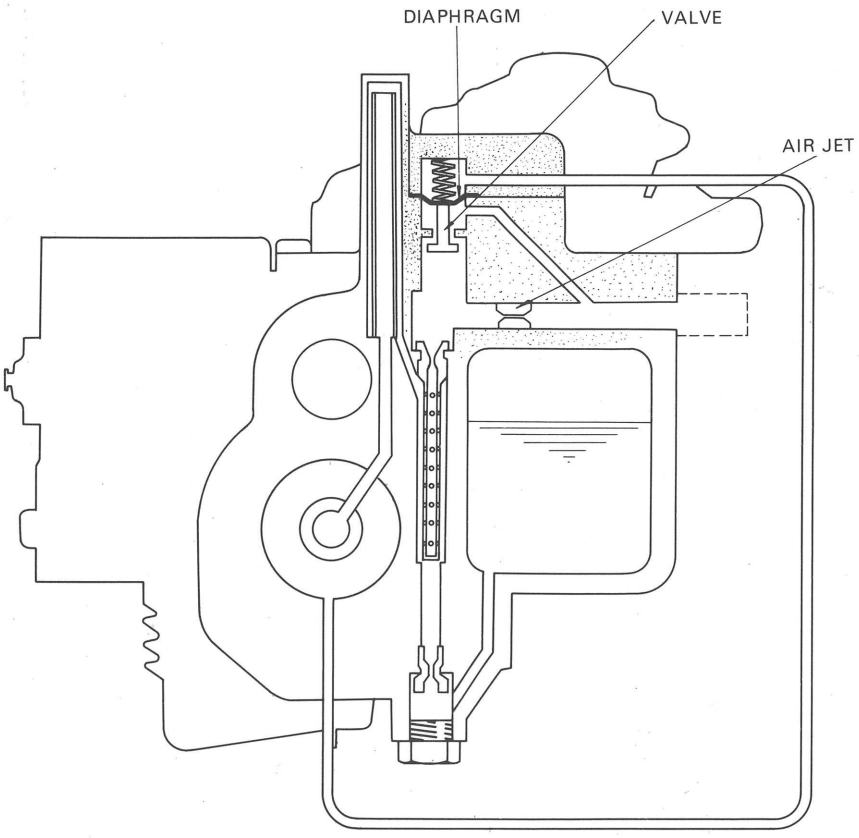


Fig. 43

The air for mixing with the fuel being supplied to the spray nozzle in the bore can reach the multi-hole main air bleed jet tube through two paths from the air filter: one extends through the diaphragm valve and the other through the air jet.

With a moderate cruising speed, the fuel-air mixture does not require extra enrichment and the diaphragm valve remains unseated to freely pass the supply air to the main air bleed jet. Since the constriction in the air jet is such as to offer a large resistance to the flow, very little air flows through it.

With a high cruising speed, the vacuum in the secondary bore is high enough to back away the diaphragm against the spring force to seat the valve. Then, the air must flow through the air jet. Since this jet meters out much less air than does the multi-hole main air bleed jet, the resultant fuel-air mixture is richer. It is with this enriched mixture that the R.E. engine sustains its high speed for high-speed cruising.

5. ELECTRICAL AUXILIARIES

5-1. Ignition system features

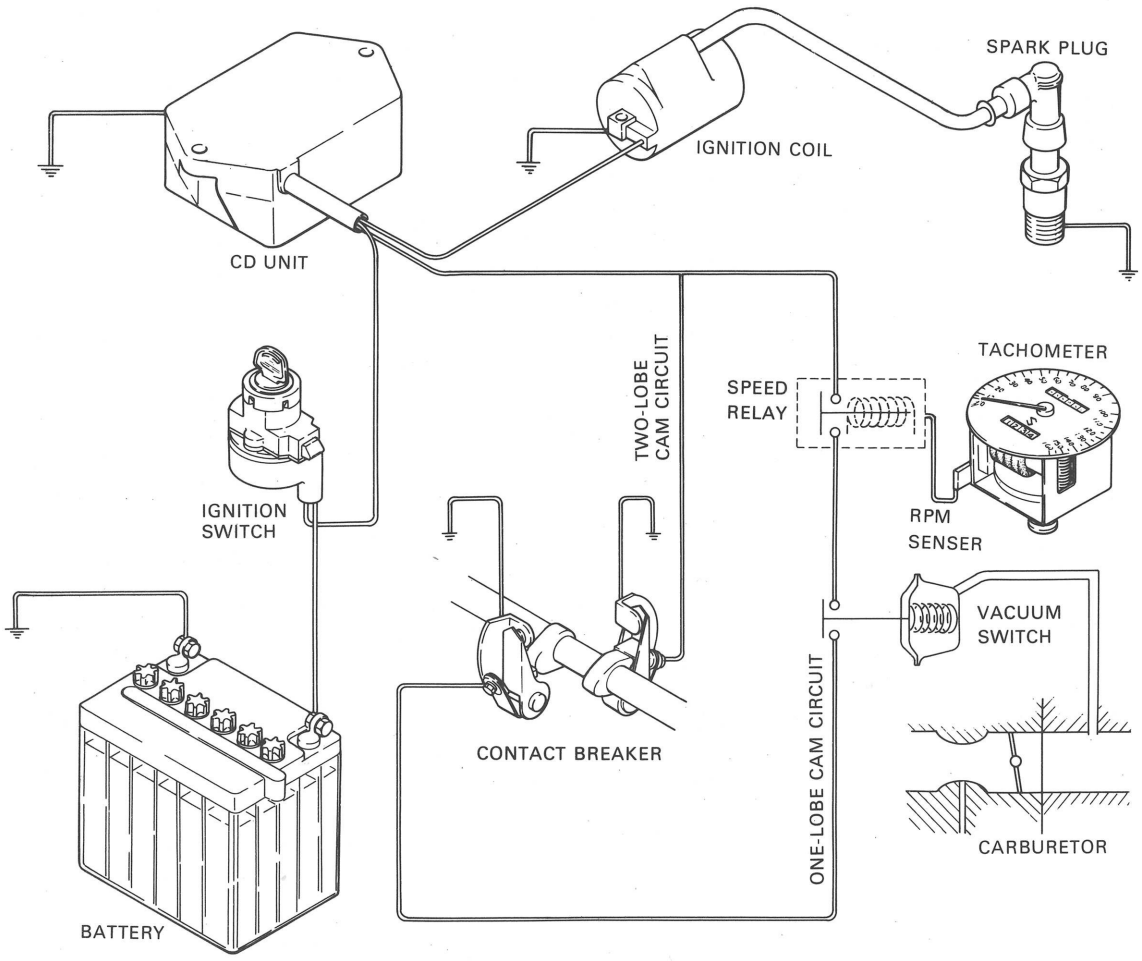


Fig. 44

The diagram above schematically indicates the capacitor-discharge ignition (CDI) system of the present R.E. In the diagram, the cam shaft, equivalent to the distributor cam shaft of the conventional ignition system, carries two cams—a two-lobe cam and one-lobe cam. The shaft rotates half as fast as the engine output shaft (eccentric shaft). Each cam operates a contact point of its own, there being two contact points. This mechanism of the system is called the contact breaker.

Note that there are two parallel circuits, one labeled as "two-lobe cam circuit" and the other as "one-lobe cam circuit", in which a speed relay and a vacuum switch are located in series. The speed relay closes only when the engine picks up speed to a preset level, which is just above the idling speed, and remains closed at higher speeds. The vacuum switch closes on high vacuum existing in the intake line.

The contact opening action of the one-lobe cam very slightly lags behind that of the two-lobe cam. Needless to say, the former cam opens its contact practically simultaneously with every other opening action of the latter.

In operation, if either the speed relay or the vacuum switch is in opened condition, the flow of current through the contact breaker is intermittently interrupted by the two-lobe cam, **once every rotation** of the output shaft. In other words, the one-lobe cam remains out of action and the ignition is initiated by the two-lobe cam.

Suppose the speed relay and vacuum switch are in closed condition. Then, the one-lobe cam initiates ignition for **every other rotation** of the output shaft, with the two-lobe cam remaining out of action. A close look at the contact breaker will explain the reason why the latter cam is cut out of service under this supposed condition, which occurs on high vacuum and at higher speeds.

It will be recalled that high vacuum (existing between carburetor and engine) occurs when, for example, the engine is in "braking" condition. Low vacuum occurs when the engine is carrying load. Thus, it may be roughly concluded that the ignition on every other rotation of the output shaft happens under high-vacuum high-speed condition of the engine.

Each current interruption is sensed by the amplifier section of the CD unit. For each interruption, the amplifier issues forth a signal for triggering on the thyristor in the CD unit. This juncture will be explained in the next sub-section.

To explain the reason why the once-every-other-rotation ignition feature is included in this ignition system, we must call the reader's attention to the low vacuum condition existing in the engine showing the effect of "braking". In such a case, each slug of fuel-air mixture coming under the spark plug does not necessarily catch fire: it may fail or may not fail to burn, resulting in an unstable, erratic running condition. By igniting one slug and skipping the next slug, the engine can be made to run more smoothly without developing the peculiar "lugging" or "jerking" which could otherwise occur in a rotary engine undergoing a change of state similar to deceleration.

5-2. CD ignition circuit

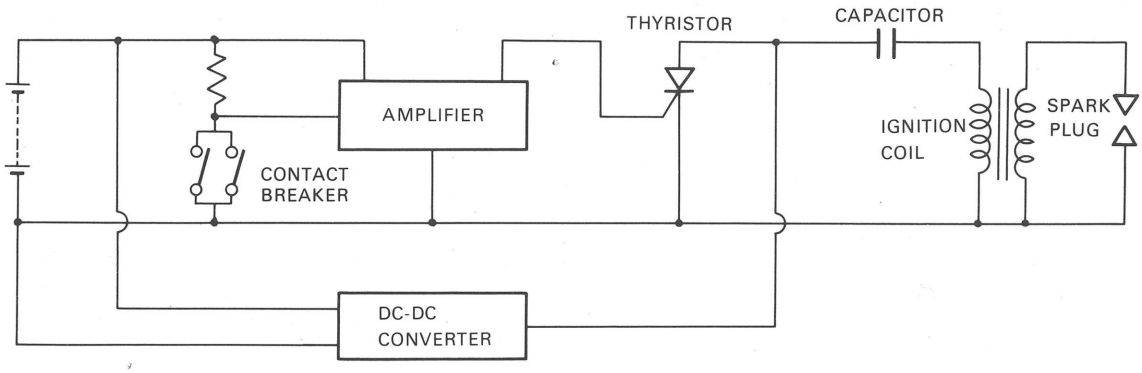


Fig. 45

Fig. 45 is a rough representation of the CD ignition circuit. The two switches stand for the two contacts in the contact breaker mentioned in the preceding subsection.

The amplifier, sensing a current interruption as mentioned previously, applies a trigger signal to the gate of the thyristor, thereby turning on this semi-conductor element.

With the thyristor now conducting, the capacitor discharge circuit is completed, so that the electric charge in the capacitor rushes out as a discharge current and flows through the primary winding of the ignition coil. From this point on, the sequence of events that take place is similar to the conventional ignition system. The difference — a very significant difference — is that the induced sparking current flows virtually in one stroke, producing a powerful spark at the gap.

It should be noted that the whole process of spark production, starting with the contact opening action and ending with the capacitor discharge and resultant sparking, is extremely short in duration because the process is largely electronic.

5-3. Fuel level pilot lamp and its check circuit

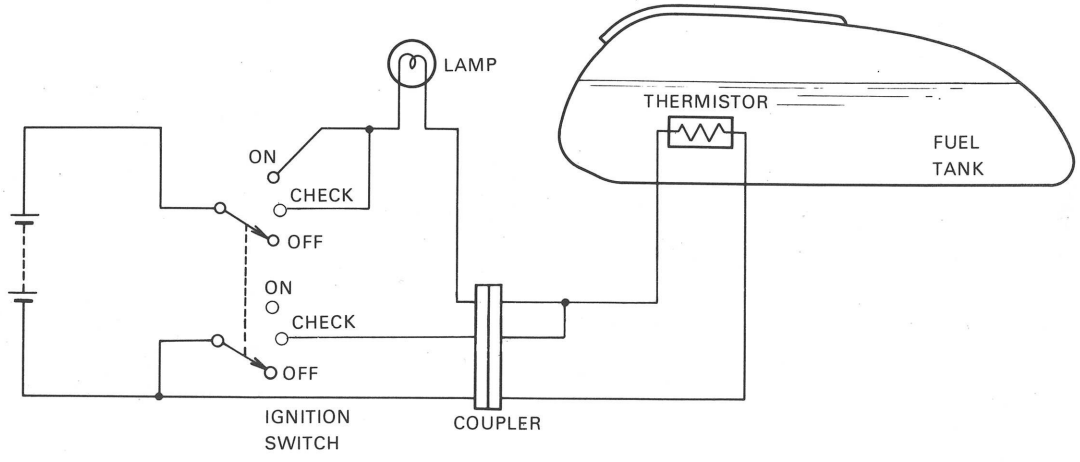


Fig. 46

A thermal resistor (thermistor) is used in the circuit to light up the pilot lamp when the fuel level is low (meaning that the thermistor unit in the fuel tank is up in the air); when the fuel is up (meaning that the thermistor unit is immersed in the fuel), the lamp remains off.

The thermistor has a resistance in it. This resistance is HIGH when the temperature of the thermistor is low, and vice versa.

Turning on the ignition switch connects the thermistor to the battery, and current flows through the pilot lamp and thermistor. This current is not large enough to light up the lamp if the thermistor unit happens to be in the state shown in Fig. 46, because the fuel keeps the thermistor cold (meaning a HIGH internal resistance).

As the fuel level falls, exposing the thermistor unit to air, the heat generated by the small current in the thermistor builds up to raise its temperature; the result is a LOW internal resistance and therefore a large current, large enough to light up the pilot lamp to signify the low fuel level condition in the tank. The heat build-up is accounted for by the fact that the heat capacity of air is smaller than that of the fuel.

Turning the switch to the check position lights up the pilot lamp instantly to indicate that the coupler is firmly plugged in and that the lamp is in good condition. If the lamp does not light up, it means either that the coupler is loose or that the lamp filament is broken.

5-4. Oil level pilot lamp and its check circuit

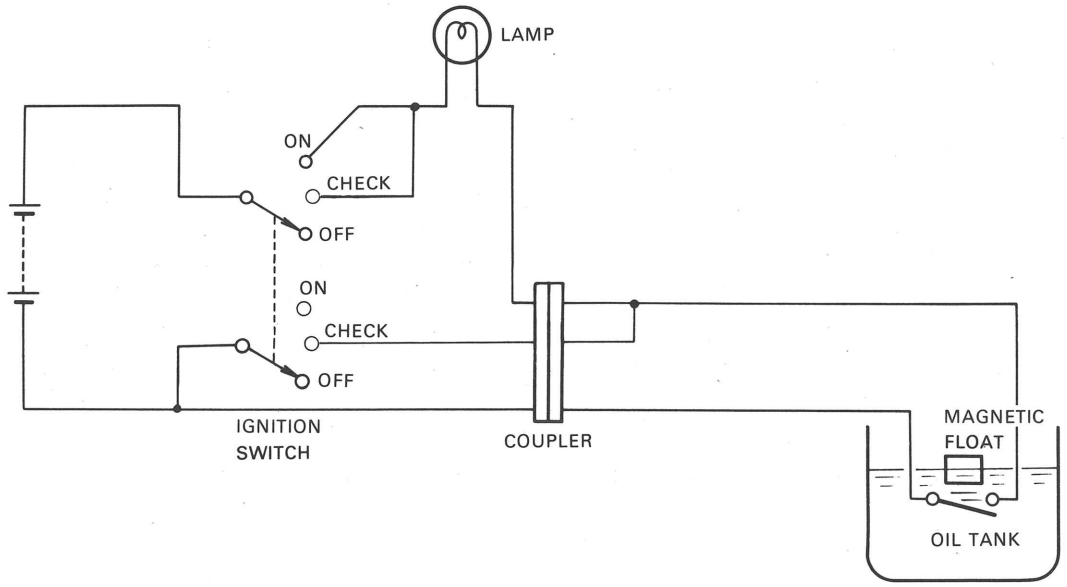


Fig. 47

A magnetic float and a switch are provided within the metering oil tank in the manner illustrated in Fig. 47. As the oil decreases in volume, the magnet moves downward and, when it comes to a certain level, the switch closes as if it were a proximity switch. When this occurs, the pilot lamp comes on as a sign of warning.

This circuit is complete with a checking provision similar to the one provided in the fuel level pilot lamp circuit.

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PRINTED IN JAPAN 74·3 (K)